

TRANSACTIONS
of the
American
Foundrymen's Association



Proceedings of the
Thirty-sixth Annual Meeting

Detroit, Mich.
May 2 to 5, 1932

VOLUME XL

EDITED BY ROBERT E. KENNEDY

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Annual Address

By the President, E. H. Ballard

*Opening Session, Thirty-sixth Annual Convention
May 2-5, 1932, at Detroit, Michigan*

PRESIDENT E. H. BALLARD: In opening this, our thirty-sixth Annual Convention, I extend cordial greetings. It is unfortunate that it became necessary to alter plans for this year's convention, as we had looked forward with unusual pleasure to having our good friends, the Materials Handling Division of the A.S.M.E., with us as exhibitors. Necessity, however, demanded action shortly after Philadelphia had been chosen as the convention city.

Our Secretary, prompted by continued business conditions, suggested that consideration be given to abandoning the exhibits this year in justice to our exhibitors, many of whom through their loyalty to the Association would have been put to much expense and in many cases possible embarrassment. Without question, as conditions have since shaped themselves, it proved a very wise change.

To the Detroit Foundrymen's Association the A.F.A. is deeply indebted for its splendid work in making preparation for this convention on such short notice. A splendid job has been done! We have before us three very busy days crowded full of extremely high grade papers and round-table discussions, all made possible by our efficient Technical Secretary and the self-sacrifice of our committees and authors of papers.

It is well recognized that our various committees and the personal contributions of many of our members have won for the A.F.A. an enviable reputation. Contributions made in past years are now reflected in many practical applications in progressive foundries at home and abroad. What a vast storehouse of useful information has been accumulated during the past thirty-six years and made available to our membership for very nominal dues!

Our new publication, *Transactions*, has met with popular favor and is serving a very useful purpose. To the staff responsible for its publication, we are indebted. I believe you will agree

that the past twelve years have witnessed more progress in the foundry industry than any similar period. Our Association has played an important part in making this progress possible. May it continue to make worth-while history.

What about the future? Surely there is much to be done if we are to maintain our place in the manufacturing cycle. The ever-increasing need for greater physical properties, and castings for higher pressures and temperatures for many applications, demands the best brains and technique it is possible to muster.

The foundry industry as a whole has not been as keen and alert as it should have been. This resulted, as many of us know too well, in suddenly finding other products taking the place of castings. I have personal knowledge of 150 tons of castings per week being replaced by fabricated units; much of this lost business was not justified from an economic standpoint.

I am confident that the tide has turned, as there are many cases where the same simple designs produced by fabrication are now being changed to castings, and combinations of fabrications and castings are being produced at a financial saving.

This change from casting to fabrication has without question been of much help to foundrymen, in that designing engineers have had their attention directed to casting design as never before, and the foundryman has been made to realize his responsibility in assisting in simplification of designs and the production of superior castings at lower cost. Much, however, has yet to be done.

You should be interested in knowing what our Association has already done and has under way to stimulate this activity in an educational way to reach the designers and users of castings. May I briefly outline these activities and allow the various committees to report in detail at our annual business meeting?

At the 1931 June meeting of the American Society for Testing Materials, a joint A. F. A. and A. S. T. M. symposium on Malleable Castings was presented. At the 1932 meeting of the A.S.T.M. a joint symposium on Steel Castings will be presented, and a joint symposium on Cast Iron has been scheduled for the A. S. T. M. meeting in June 1933, to be followed by a symposium on Nonferrous Castings in 1934.

During the past year the A.F.A. has cooperated with district foundry associations in holding meetings to which members of engineering societies were invited. Four such meetings were held,

in Philadelphia, Pittsburgh, Chicago, and Seattle, Wash. Two are tentatively scheduled for Birmingham, Ala., and Toronto, Canada.

Progress is being made in developing a Handbook on Cast Metals for engineers and foundrymen. Much material has been made available through the excellent cooperation of the Gray Iron Institute, Steel Founders' Society of America, Malleable Iron Research Institute, and our Nonferrous group. It is hoped that certain sections of these data can be published soon and be revised from time to time and kept up to date as an authoritative reference. This, to my mind, is one of the most important pieces of work we have before us.

The Joint Committee on Foundry Education in Engineering Schools has sponsored the preparation of a series of lectures on cast metals to be presented before engineering student groups. This committee also has formulated a recommended course of foundry practice for engineering curricula. The aim of our Association should be to preach the gospel where and when it will do the greatest good, promulgating authentic information regarding the benefit of cast metals.

I would also mention the timely work done by our Executive Secretary in calling together representatives of six national associations in the foundry industry to give consideration to the report of a committee of the National Safety Council and the U. S. Department of Health, on Health Protection in Sandblasting and Metallic Abrasive Blasting.

The first meeting of the Foundrymen's Committee was held in Chicago on March 8. At that time a committee was appointed to appear before a meeting of the executive committee of the National Safety council on March 14, to protest the acceptance and publication of this report until representatives of the foundry industry had further opportunity to consider it and make recommendations for constructive revision.

The extension of time was granted and a second meeting of the Foundrymen's Committee held in Chicago on March 29, at which time a committee was appointed to review the report and make recommendations. This subject is of vital importance to all our members, and I am sure more will be heard about it later.

A number of years ago a man of international reputation made this statement: "The profits of tomorrow will be made from the waste of today." How true a saying, evidenced by innumer-

able articles produced today from waste and by-products previously thrown away. We in the foundry have an opportunity to recover much that is unnecessarily wasted both in time and materials.

Our membership has decreased this year, as we might expect. To our present members may I express the sincere appreciation of your President and Directors for your loyal support during times of stress. The same keen appreciation is expressed to all our committee members, authors and session leaders; also to our ever-loyal group of foundry equipment manufacturers. My personal appreciation is expressed to our loyal and efficient office staff, who have met present business conditions and reduced running expenses of the office by at least 30 per cent.

This past year our Association has carried on with strife and turmoil all about us. I trust we shall continue to carry on, completing many projects now under way and constantly initiating new ones. It is my sincere wish that the sun will soon shine on the business world and that our next convention may be held as scheduled under the most favorable conditions possible.

Have continued faith in your country, your business and yourself.

Annual Business Meeting

AMERICAN FOUNDRYMEN'S ASSOCIATION

HOTEL STATLER, DETROIT, MAY 5, 1932

President E. H. Ballard presiding.

PRESIDENT E. H. BALLARD: In opening our annual business meeting, we will deviate somewhat this year in that it has seemed desirable for the chairmen of the various groups to make their own reports. Accordingly, the first report is that of the Nonferrous Division, by Chairman Sam Tour.

SAM TOUR: The Nonferrous Division this year has been busy reorganizing along the lines of the new rules and regulations we have drawn up, which are somewhat different from those of other A.F.A. divisions. We are carrying out an experiment to find out whether the divisional type of organization we have set up will be adaptable to other divisions.

The Nonferrous Division is proceeding along the lines of its general activities as followed in the past. We are organizing a strong recommended practice committee to work on the new Cast Metals Handbook.

*The report of the Gray Iron Division next was presented,
by Chairman H. Bornstein.*

H. BORNSTEIN: The Gray Iron Division has worked along the lines of research in cast iron in the development of recommended practices, and has submitted some of these recommended practices to the Association. The division has cooperated with the Bureau of Standards in research work there, as on liquid shrinkage and the development of practical fluidity tests for casting metals.

The Gray Iron Division has recommended that the A.F.A. and A.S.T.M. sponsor a joint symposium on physical properties of cast iron at the 1933 meeting of A.S.T.M., which will be held in Chicago, and a committee has been organized to develop such a symposium. Furthermore, we feel there is a need of educating foundrymen in the testing of cast iron, and it is planned, together with the A.S.T.M., to present a symposium at the 1933 annual meeting of A.F.A. on the testing of cast iron and the significance of tests in cast iron production.

President Ballard next declared that, in the absence of Frank M. Robbins as Chairman of the Malleable Iron Division, E. E. Griest had been scheduled to present that division's report; but that, since Mr. Griest was not present, the report would be presented when he came in.

President Ballard also stated that in the absence of D. M. Scott as Chairman of the Steel Division, the report of that division would be deferred until later; and that, in the meantime, the report of the Executive Secretary would be heard.

SECRETARY C. E. HOYT: We are assembled in Convention at a time when industry in general and our own in particular is experiencing the greatest depression since the organization of the Association in 1896. These unusual conditions made it advisable to revise, in February of this year, the plans developed in the summer and early fall of 1931 for holding a Convention and Exposition in Philadelphia.

A convention of our Association had not been held in the East in four years. The new Municipal Auditorium in Philadelphia offered the most complete accommodations ever placed at our disposal, and in the early months of our campaign we planned to make full use of these facilities in staging a great Convention and Exposition. These plans included an invitation to the Materials Handling, Management and Maintenance groups of the American Society of Mechanical Engineers to meet in joint convention with us, and to the American Gas Association to cooperate in assembling a representative exhibit of gas burning equipment for foundries. These invitations were officially accepted.

Then with the Philadelphia Foundrymen's Association, Philadelphia Section of the A.S.M.E., and Philadelphia members of the American Gas Association organized to cooperate, all that seemed necessary to do was to catch and lay hold of that elusive thing, Good Business, which seemed always to be just around the corner. When it became apparent to us that this very much desired thing, Good Business, could not be captured or laid hold of soon enough to insure an attendance of buyers that would fully justify exhibitor participation, we felt that we should, in all fairness, relieve exhibitors of any obligation by canceling all exhibit plans for this year.

Without an Exhibit we would not have need of the unusual facilities offered in the Philadelphia Auditorium. Therefore, it was decided to meet in some other city, holding Philadelphia in reserve for another year.

It should be stated here that cancelation of the Exhibit was

not at the request of individual exhibitors or any group of exhibitors. It was prompted out of consideration for those exhibitors who have so loyally and whole-heartedly cooperated with the A.F.A. in past years. As evidence of this cooperation we quote from a resolution adopted at the annual meeting of the Foundry Equipment Manufacturers' Association on February 5:

"Resolved, by members of the Foundry Equipment Manufacturers' Association in their annual convention assembled, that the holding of this combined Convention and Exposition, under the name of the Foundry and Industrial Exposition, is approved as affording opportunity to display, demonstrate and explain sundry equipment and supplies of value in castings manufacture and the contributory processes thereto; and be it further

"Resolved, that inasmuch as the plans for this Exposition and the molding of industry opinion and furthering of the technique of foundry operations is the primary object of such activity, the Association offers its cooperation to the Officers and Directors of the American Foundrymen's Association in the attainment of its aims."

The report of this meeting was hardly in the mails before announcement of cancelation of the Exhibit was made. When it became known that there would be a change in convention city, we were besieged with invitations. It was most important that in whatever city we selected there be a group of foundrymen to take over the program which had already been set up by members of the Philadelphia Foundrymen's Association, and a section of the A.S.M.E. that would carry out the program developed by the Philadelphia section of the A.S.M.E.

We wish here to acknowledge our indebtedness to the Detroit Foundrymen's Association who, under the leadership of President J. L. Mahon and Secretary Neil McArthur, quickly organized to do the honors as hosts to visiting foundrymen, and to Willis B. Thomas, Chairman of the Detroit section of A.S.M.E., and Jervis B. Webb of Detroit, Chairman of the Materials Handling Division, who with their committees assumed the responsibility for staging the meetings here of the A.S.M.E. groups.

Finances

As the income from the department of exhibits finances approximately 40% of the general overhead expenses, salaries, clerical, rent, publicity, etc., it can readily be seen that without any income from exhibits during this fiscal year we will show, when

our books are closed June 30, a very definite operating loss. This will be increased by losses in membership which we have sustained in common with practically all associations and societies during the past year. To offset this we have put into effect economies, including reduction in rent, in publication costs and in staff salaries. The salary reductions now in effect range from 30% to 50%, the average reduction for our staff being 41%.

Reduced Budget

While our tentative budget for the year 1932-33 provides for reduced operating costs of approximately \$17,000, there will be only a minimum curtailment of activities. The publication of the *Transactions* bi-monthly instead of monthly will result in an estimated saving of \$4600.00. In this connection it will be our recommendation that an editorial committee be appointed to select the material to be published in the *Transactions* and to review papers for the purpose of deleting unnecessary sections.

Symposiums on Castings

At the 1931 June meeting of the American Society for Testing Materials, a joint A.F.A. and A.S.T.M. Symposium on Malleable Castings was presented. At the June 1932 meeting of the A.S.T.M., a joint A.F.A. and A.S.T.M. Symposium on Steel Castings will be presented, and a joint A.F.A. and A.S.T.M. Symposium on Cast Iron has been scheduled for the A.S.T.M. meeting in June, 1933.

District Foundry and Engineering Group Meetings

During the coming year we will lend our cooperation in organizing joint meetings of district foundry associations and engineering groups to discuss the design of castings and recent developments of cast metals which broaden their fields of application in engineering construction. These would be similar in character to the meetings held this year at Philadelphia, Pittsburgh, Chicago and Seattle.

Cooperation of American Society of Mechanical Engineers

During the past year Technical Secretary R. E. Kennedy has been appointed Secretary of the Foundry Practice Committee of the A.S.M.E. This committee has as its function the organizing of sessions on foundry subjects at the following meetings:

- (a) The Annual A.S.M.E. Convention.
- (b) Regional A.S.M.E. Meetings.
- (c) Sectional A.S.M.E. Meetings.

A session has already been approved for the December, 1932, national meeting of the A.S.M.E., at which it is planned to have a Symposium on Recent Developments in Various Cast Metals.

Handbook on Cast Metals

Committees of the various divisions of A.F.A. and trade organizations are accumulating material for a Handbook on Cast Metals, which it is expected will be of great value to engineers and designers, student engineers and foundrymen. It is hoped that during the coming year some sections of the Handbook will be ready for publication.

Lectures for Engineering Schools

The Joint Committee on Foundry Education in Engineering Schools is sponsoring the preparation of a series of lectures on cast metals. It is proposed that these be prepared in mimeograph form and slides of the illustrations made. Copies of the lectures, together with the slides, will be available for each lecture and our office will endeavor to secure men in the vicinity of the various schools to present the lectures.

General Committee Activities

The general committee activities under the various divisions will be carried on and efforts will be made to schedule meetings at times and places that will enable us to keep costs down to the minimum.

Sand Research

Annually there has been an appropriation for Sand Research Committee work. The committee hopes during the coming year to conduct their work by correspondence and has not made any formal request for funds for research.

Membership

Our book membership on June 30, 1931, was 2368. Since July 1 we have had 271 resignations, dropped 116 delinquents and lost

4 by death, a total of 391. To date of April 15 we have added 40 new members, reducing the loss to 351 or 14.8%.

This is not an all-time record loss in membership, for we find that in the year 1898-99 the Association suffered a loss in membership of 45.2%. In the year 1921-22 we had a membership loss of 10.8%. Many of the resignations received during the past nine months are tentative in character, with promises of renewal when conditions improve.

I am sure we can all have a sympathetic understanding of the feelings of President Ballard which prompted him to say in writing us on the perplexing problem of change in convention plans:

"I sometimes wonder why it was my lot to be elected President in a year so beset with trouble, uncertainty and lack of opportunity to do many things which I had in mind and which I desired to do while President of A.F.A. Notwithstanding all this, they are mere incidents as compared with the real problems in business with which we are all confronted today."

I can truly say, without in any way disparaging the interest and earnestness of any of the splendid men who preceded Bert Ballard as President, that we never have had a President of A.F.A. more ambitious for the success of the Association, more constructive in suggestions, and at all times prompt to respond to our every request for advice and help. It has been a joy and inspiration to work under his direction.

To President Ballard and to all members of the Board of Directors, we of the A.F.A. office staff wish to express sincere appreciation for their help and encouragement. To them and to all A.F.A. members we express the hope that the coming year will offer more of encouragement and satisfaction than has the past year.

The resolution on awarding of the John A. Penton Gold Medal to the late LaVerne W. Spring was presented by past-President R. A. Bull, as follows:

R. A. BULL: It is at the same time a gratifying privilege and a saddening responsibility to attempt to express, on behalf of the Association, any sentiments in connection with the award that has been made to LaVerne W. Spring. As the President has announced, the medal has already been presented to Mrs. Spring with appropriate expressions of the esteem in which he was regarded by the members of this Association.

It happened to be one of Verne Spring's intimate friends. During the ten years of my residence in Chicago, it was my good for-

tune to be in constant contact with him. We had very close relations together on several committees of the A.S.T.M., the activities of which related in an important way to the manufacture of castings. In that way I learned to know the man thoroughly and to admire greatly his technical ability and his fine personal characteristics.

I make the confession that I first had contact with the foundry industry some forty years ago and have met a great many foundrymen since, but in that long period of time I have never known a man in the industry who combined in a more significant degree, industry, intelligence and sincerity. I think that is the finest tribute I personally am able to pay the man.

Mr. Bull then read the following resolution he had prepared as chairman of a committee on memorial resolutions:

The death of LaVerne W. Spring, which occurred March 2, 1932, terminated the career of an outstanding student of the manufacture and properties of cast metals. As a faithful servant of the Crane Company, which has supported the American Foundrymen's Association by membership since it was organized in 1896, Mr. Spring conducted many investigations which resulted in valuable information for founders and consumers of gray iron, malleable iron, steel and non-ferrous castings.

The results of these researches, presented before various technical societies, coupled with other publications written by our former colleague, brought him many honors, including the John A. Penton Gold Medal awarded by this Association.

Not alone in skillful technical labors was the life of LaVerne Spring significant. It was signalized by an honesty of purpose, a kindliness of spirit, and an abhorrence of deception which made our foundryman-friend truly great.

For the reasons stated, therefore, be it

Resolved, by the members of the American Foundrymen's Association, in annual convention assembled, that this written tribute to LaVerne W. Spring be spread on the permanent records of this Association, in appreciative testimony of important contributions made during a period of more than a quarter century, to the art of castings manufacture, by our departed fellow foundryman;

Resolved, that a copy of these resolutions be transmitted to the Crane Company, now deprived of the services of their former Chief Chemist and Metallurgist, in token of our remembrance of the company's assistance to the objectives of this Association, through Mr. Spring's labors; and be it further

Resolved, that a copy of these resolutions be given to Mrs. LaVerne W. Spring, as an inadequate but sincere expression of our deep sympathy for her and her children in this time of sorrow. We doubt not that the life-record of our departed friend will be an inspiration to his loved ones. And we hope our appreciation of the high character and marked ability of the deceased husband and father will give some measure of comfort to those who are bereaved.

Presentation of the Wm. H. McFadden Gold Medal of the A.F.A. to Dr. H. W. Gillett, Battelle Memorial Institute, Columbus, Ohio, was made by past-President G. H. Clamer, as follows:

G. H. CLAMER: It was about 1911 that I first heard the name of Dr. Gillett. At that time I was attending a small gathering of metallurgists called to Buffalo by Dr. Parsons, now secretary of the American Chemical Society but at that time chief chemist for the Bureau of Mines. Dr. Parsons was seeking a man for the position of alloy chemist with the Bureau, and he had called this group together in consultation to pick the man.

A number of candidates were discussed, of course, but Dr. Gillett was decidedly outstanding among them and there was no question about the choice. Dr. Gillett received the appointment and thereafter was in a position to serve the foundry and metallurgical industries of the country in a decidedly beneficial way.

During that time I came in contact with him on many occasions, because we had problems of mutual interest. I was able to watch his progress and see the results obtained, and I know of no work that was done, at least in the nonferrous field, that compared with his. I refer to an investigation of the brass melting practice of the foundries and rolling mills of the country.

Dr. Gillett was trained as a chemist at Cornell University, and between his undergraduate and graduate work served on the staff of Thomas A. Edison, Inc., and Arthur D. Little, Inc. After completing his graduate work in 1910, he began twenty years of metallurgy by first installing the research and control laboratory for the Aluminum Castings Co., where the problems dealt with aluminum, brass and bronze castings and foundry practice.

He then went into the government service, spending twelve years with the Bureau of Mines as alloy chemist. His work involved a survey of brass melting practice and the study of electric brass melting, culminating in the development of the rocking electric furnace which has found wide foundry use for brass and bronze and is being adapted to special problems in gray iron. The

war brought further metallurgical problems and Dr. Gillett was assigned to the study of electric smelting for the utilization of low-grade domestic manganese ores, and later to the study of special alloy steels. This work is recorded in many publications of the Bureau of Mines.

In 1924 Dr. Gillett moved on to the Bureau of Standards as Chief of the Division of Metallurgy and guided the work of this division for five years. This involved both scientific work and contact with problems of the metallurgical industries over a wide field of ferrous and nonferrous metallurgy.

In July, 1929, he became director of Battelle Memorial Institute, Columbus, Ohio, a research institution dealing with metallurgy and fuels, both on its own endowment in fundamental work and cooperative research supported by sponsor firms and groups in the industry. At the same time he took up the work as editorial director of the publication *Metals and Alloys*, since the trustees of the Institute felt that the aims and objects of *Metals and Alloys* were closely similar to those of the Institute itself.

Dr. Gillett is a member of American Foundrymen's Association, American Chemical Society, American Electrochemical Society, American Society for Testing Materials, American Institute of Mining and Metallurgical Engineers, British Institute of Metals, American Society for Steel Treating and American Welding Society. He has not only been a member of these technical societies but also has been a decidedly active member and has contributed many papers to their meetings.

I have the distinct pleasure, Dr. Gillett, of advising you that upon recommendation of the Board of Awards of the American Foundrymen's Association, and vote of the Executive Committee of the Association, you have been awarded the Wm. H. McFadden Medal for 1932, and I take great pleasure in presenting it to you with the certificate accompanying it.

In receiving the Wm. H. McFadden Medal, Dr. Gillett responded as follows:

DR. H. W. GILLETT: In accepting the McFadden Medal, I do so not as a personal matter but as representing a considerable number of cooperators who have worked on foundry problems away back from the early days of the Aluminum Castings Co. here in Detroit and through the Bureau of Mines, the Bureau of Standards and now the Battelle Memorial Institute. It just happens that I have been connected with the work of a good many people,

and if any of that work has been helpful to the foundry industry, they will be as pleased as I am by this recognition, not as a personal matter but as a representative of quite a group of people. I thank you and the American Foundrymen's Association.

The report of judges on the 1932 Molding and Pattern Making Contests for Apprentices next was presented by Technical Secretary R. E. Kennedy, as follows:

R. E. KENNEDY: The annual apprentice contests were conducted this year as usual with practically the same number of entries and representatives from the same geographical groups, from Milwaukee, Wis. and Moline, Ill., up to Schenectady, N. Y. and down into Virginia.

Winners of the apprentice contests then were named as selected by the judges, the report accepted, and delivery of prizes authorized.

The report of the Committee on International Relations then was presented by Chairman D. M. Avey, as follows:

D. M. AVEY: The International Relations Committee early in the year sensed the fact that it would be impossible to assemble a large representative body to attend the Fourth International Congress in Paris this Fall. Accordingly, after communication with the French sponsoring association through our European representative member of the committee, Mr. Delpont, apprising them of that fact, we considered the matter from the standpoint of whether we should definitely abandon the idea of an official party.

This action has been recommended by the International Relations Committee, but with the proviso that the office of the American Foundrymen's Association will be glad to act as a clearing house for all individuals who expect to make the European journey this Fall. Furthermore, our participation through exchange papers and through representation by outstanding members of the Association will serve to maintain contact during this unfortunate season.

Just by way of announcement—and we strongly urge those who have the opportunity, to avail themselves of this occasion—the meeting will be held in September with two short tours organized immediately before the convention, from September 8 to 12, with the meeting proper from September 14 to 17, followed by two short tours which will end the latter part of September.

We have received this morning the official greetings of the French Foundrymen's Association in the form of a cablegram from Mr. Ronceray, president of the French association, sending

his best wishes and hoping that many members will be able to accept the invitation to attend the Congress in September.

Resolutions next were presented by D. M. Avey as chairman of the Resolutions Committee, condemning governmental waste and urging greater economy, and to the Detroit Foundrymen's Association for contributing to the success of the convention.

The report of the 1932 Nominating Committee was presented by Executive Secretary C. E. Hoyt as follows:

C. E. HOYT: Under date of January 29 the Executive Secretary mailed all members a report of the meeting of the Nominating Committee held in Cleveland January 15, attended by past-Presidents S. T. Johnston and N. K. B. Patch, and members M. A. Blakey, H. F. Seifert, Frank A. Sherman and Ralph H. West, elected by letter ballot of the members. The announcement stated that past-President S. T. Johnston, Chairman of the committee, had certified that the following were nominated:

For President, to serve one year—

T. S. Hammond, President, Whiting Corporation, Harvey, Ill.

For Vice-President, to serve one year—

Frank J. Lanahan, President, Fort Pitt Malleable Iron Co., Pittsburgh.

For Directors, each to serve three years—

E. H. Ballard, General Foundry and Pattern Shop Superintendent, General Electric Co., West Lynn, Mass.

H. Bornstein, Director, Testing and Research Laboratories, Deere & Co., Moline, Ill.

S. B. Cuthbert, Superintendent of Foundries, Edgar Thomson Works, Carnegie Steel Co., Braddock, Pa.

David Evans, President, Chicago Steel Foundry Co., Chicago.

Franklin G. Smith, President, Osborn Mfg. Co., Cleveland.

The Secretary certifies that no other nominations for officers or directors were made as provided for in the by-laws.

Secretary Hoyt then moved the election of the above-named nominees for officers and directors. The motion being duly seconded, an unanimous vote was cast in favor of the nominees; President Ballard then declared them duly elected and introduced the new officers-elect to the members of the Association.

Recommendations of the Board of Directors regarding honorary membership then were presented by Secretary C. E. Hoyt, as follows:

SECRETARY C. E. HOYT: It is my privilege to report that the Board of Directors recommend the election of E. H. Ballard to

Honorary membership in the Association at the expiration of his term of office as President. The By-Laws provide that election shall be by vote of the members at a regular meeting and it would, therefore, be in order for Vice-President Hammond to entertain a motion at this time.

R. A. BULL: As the senior past-president present, I believe it is my privilege to offer such a motion and I do appreciate that privilege. I have had the opportunity of observing how Mr. Ballard has kept his poise under disturbing conditions. I think he has done a fine job and I am happy to move his election to Honorary membership in the American Foundrymen's Association.

VICE-PRESIDENT T. S. HAMMOND: A second to that motion hardly seems necessary. We will have a rising vote. . . . The vote is unanimous and I declare Mr. Ballard elected to Honorary membership in A.F.A.

PRESIDENT E. H. BALLARD: I have only one word to say in recognition of this vote and that is that the word "honorary" implies to me exactly what it means in the English language. It is indeed a great honor to me to receive this recognition. I appreciate it very deeply.

If there is no unfinished business or no new business to come before the meeting, we will declare the meeting adjourned.

Minutes of Board Meetings

Included herein are minutes of the following meetings of the Board of Directors and the Executive Committee of the Board held during the calendar year, 1932:

February 25—Special Meeting of the Executive Committee, held in Pittsburgh.

May 5—Final meeting of the 1931-32 Board of Directors, held during the Detroit Convention.

May 5—First meeting of the 1932-33 Board of Directors, held during the Detroit Convention.

November 17—Meeting of the Executive Committee, held in New York.

These minutes constitute a report of all official meetings of the Association held during the calendar year 1932, except for the Annual Business Meeting held May 5 during the Detroit Convention and abstracted herein on pages ix to xx, inclusive.

* * *

Minutes of Special Meeting, Executive Committee, 1931-32 Board of Directors

AMERICAN FOUNDRYMEN'S ASSOCIATION

WM. PENN HOTEL, PITTSBURGH, FEB. 25, 1932

Vice-President T. S. Hammond presiding.

Roll Call

The following members of the Executive Committee responded to roll call: Vice-President T. S. Hammond; Directors D. M. Avey, Frank J. Lanahan, N. K. B. Patch, Fred L. Wolf, C. E. Hoyt. Absent, President E. H. Ballard.

The Executive Secretary reviewed developments *re* convention plans in the short interval between February 12—when he wrote President Ballard that developments in the previous two or three days had convinced him that we were faced with making an important decision as to whether or not we should modify our plans for the 1932 Convention—and February 20, when he submitted his report to the Board of Directors.

He stated further that in this communication to the Board he had reported conferences held in Philadelphia with Director D. M. Avey and past-President G. H. Clamer; in New York with P. T. Wetter, Assistant Secretary of A.S.M.E., and with members of the Materials Handling Division of A.S.M.E., sponsors of the Industrial Congress scheduled concurrently in Philadelphia with the A.F.A. Convention; in Boston with President E. H. Ballard, and further conferences in New York; followed by conferences with Director Frank J. Lanahan in Pittsburgh, and with Director D. M. Avey and with S. C. Vessy, W. W. Sly Mfg. Co., Cleveland, and Franklin G. Smith, Osborn Mfg. Co., Cleveland, in Cleveland.

The Executive Secretary stated further that as a result of these reported conferences and interviews the Board of Directors by letter ballot had authorized the Executive Committee to cancel all arrangements for holding the 1932 Convention and Exposition of the Association in Philadelphia, May 2-6, and to select some other city than Philadelphia for holding a Convention without an exhibit during the first week of May, and that was the purpose for which this meeting was called.

The Secretary read a communication from President Ballard expressing regret for his absence, and stating that he would be happy to abide by the decision of those present.

The Secretary announced that invitations for the 1932 Convention had been received from the convention bureaus of Buffalo, Chicago, Cincinnati, Cleveland, Detroit, Grand Rapids, Mich., Milwaukee, Pittsburgh, St. Louis, and Toronto, Canada. Following a complimentary luncheon given by the manager and promotion manager of the Wm. Penn Hotel, the members of the committee were shown the convention and exhibit facilities of this hotel.

The Committee then went into session to consider the invitations. Representatives of the convention bureaus of Cleveland and Detroit appeared before the committee and were heard.

The Secretary pointed out that any change in the previously approved program would affect plans for the annual meeting of the Industrial Congress sponsored by the Materials Handling, Management and Maintenance divisions of A.S.M.E., and that it was important their interests be given every consideration. He stated that an exchange of telegrams and telephone conversations with P. T. Wetter had developed the fact that Detroit would be acceptable to them. However, it should be mentioned that Mr. Wetter urged that first consideration be given the interests of the A.F.A.

Following consideration of all invitations received, the committee by unanimous vote decided to accept the invitation of Detroit and instructed the Executive Secretary to proceed to that city and complete negotiations for holding the Annual Convention of the Association during the dates May 2-5, 1932, without an exhibit.

A vote of thanks was extended the management of the Wm. Penn Hotel for courtesies shown, and on motion the meeting stood adjourned.

Respectfully submitted,

C. E. Hoyt, *Executive Secretary.*

Minutes of Annual Meeting 1931-32 Board of Directors

AMERICAN FOUNDRYMEN'S ASSOCIATION
HOTEL STATLER, DETROIT, MAY 5, 1932

President E. H. Ballard presiding.

Roll Call

The annual meeting of the Board of Directors followed the annual Alumni Dinner, attended by past-Presidents W. H. McFadden (1906), R. A. Bull (1915, 1916), B. D. Fuller (1918), W. R. Bean (1922), and S. W. Utley (1927, 1928); past-Directors A. E. Hageboeck, T. W. Pangborn, and S. C. Vessy; Directors-elect David Evans, Franklin G. Smith, and H. Bornstein; Technical Secretary R. E. Kennedy, and Executive Secretary C. E. Hoyt.

The following directors responded to roll call: President E. H. Ballard; Vice-President T. S. Hammond; Frank J. Lanahan, Arnold Lenz, Delos H. Wray, C. S. Anderson, Fred Erb, R. M. Maull, D. M. Scott, Dan M. Avey, A. G. Storie, Fred L. Wolf. Absent, Harold S. Falk, S. T. Johnston, H. R. Culling, W. D. Moore, N. K. B. Patch.

Greetings and messages were received from members of the Advisory Board unable to attend, and President Ballard appointed a committee to telegraph greetings from those present to past-President N. K. B. Patch.

On motion, reading of the minutes of the annual meeting of the Board held July 9, 1931, was waived.

Report of Executive Secretary-Treasurer

The Secretary's report reviewed activities of the past year and outlined plans for the coming year. The book membership of 2017 showed a net loss of 351, or 14.8 per cent, for the period July 1, 1931, to April 15, 1932.

The Treasurer, reporting on the financial condition of the Association, stated that when the books were closed at the end of the fiscal year, June 30, 1932, they would show, as a result of having canceled the 1932 Exhibit, a heavy operating loss, as with the present set-up the income from exhibits finances approximately 40 per cent of the general operating expenses, salaries, clerical help, rent, publications, etc.

The Treasurer stated that, in an effort to offset losses in income, the officers and Finance Committee had put into effect rigid economies, with salary and clerical reductions ranging from 30 to 50 per cent, and that the average reduction for the office staff in the year totaled 41 per cent.

On motion duly seconded, reports of the Executive Secretary and Treasurer were accepted and ordered filed.

Report for Executive Committee

The Secretary reported that two meetings of the Executive Committee

had been held during the year, the first in New York on Nov. 19, 1931, with all members present, and the second in Pittsburgh on Feb. 25, 1932, with all members present except President E. H. Ballard.

On motion duly seconded, reading of the minutes of these meetings was waived and all acts of the Executive Committee approved.

Report of Actions Taken by Letter Ballot

The Secretary reported that during the year the Directors had approved by letter ballot the action of the Special Convention Committee in selecting Philadelphia as the place of the 1931 annual meeting; recommendations of the special committee appointed to select ten members whose names were to appear on the official ballot for election of four members of the Nominating Committee; recommendations of the Board of Awards that a John A. Penton Gold Medal be awarded LaVerne W. Spring, Crane Company, Chicago, and a Wm. H. McFadden Gold Medal to Dr. H. W. Gillett, Battelle Memorial Institute, Columbus, Ohio; election of Messrs. Spring and Gillett to Life Membership; and recommendations of the officers that all exhibit plans for 1932 be canceled and the Executive Committee authorized to select a city and name the date for holding an annual convention without an exhibit.

Report of Manager of Exhibits

The Manager of Exhibits stated it should be recorded that the 1932 Foundry and Industrial Exposition planned for Philadelphia was canceled when it became apparent to the officers and directors that because of general business conditions it would not be fair to our exhibitor companies to call upon them to stage exhibits; and further, that this action and subsequent action restricting room exhibits had received unanimous approval of members and exhibitors.

Report of Divisional Activities Correlation Committee

T. S. Hammond, Chairman of the Divisional Activities Correlation Committee, reported action taken at a meeting held Tuesday evening, May 3. On motion duly seconded, the report was accepted and referred to the incoming Board for action.

Election of Officers

The Executive Secretary reported that at the annual business meeting of the Association held May 5, the following officers and directors were declared elected:

President, T. S. Hammond, Whiting Corp., Harvey, Ill.; *vice-president*, Frank J. Lanahan, Fort Pitt Malleable Iron Co., Pittsburgh; *directors*—E. H. Ballard, General Electric Co., West Lynn, Mass.; H. Bornstein, Deere & Co., Moline, Ill.; S. B. Cuthbert, Edgar Thomson Works, Carnegie Steel Co., Braddock, Pa.; David Evans, Chicago Steel Foundry Co., Chicago; Franklin G. Smith, Osborn Mfg. Co., Cleveland.

President Ballard again expressed appreciation for the cooperation received during his term of office from all members of the Board, com-

mittees of the Association, and authors. He then introduced President-elect T. S. Hammond, as the new president of A.F.A., and turned the meeting over to him.

President Hammond responded and then declared the meeting of the 1931-32 Board of Directors adjourned, and announced that the first meeting of the 1932-33 Board would be convened immediately.

Respectfully submitted,

C. E. HOYT, *Executive Secretary.*

Minutes of First Meeting 1932-33 Board of Directors

AMERICAN FOUNDRYMEN'S ASSOCIATION
HOTEL STATLER, DETROIT, MAY 5, 1932

President T. S. Hammond presiding.

Roll Call

On assuming the chair, President Hammond addressed the retiring president and directors and then called the roll, the following officers and directors responding: President T. S. Hammond; Vice-President Frank J. Lanahan; Directors C. S. Anderson, Fred Erb, R. M. Maull, D. M. Scott, Dan M. Avey, A. G. Storie, Fred L. Wolf, E. H. Ballard, H. Bornstein, David Evans, Franklin G. Smith; Technical Secretary R. E. Kennedy, Executive Secretary C. E. Hoyt. Absent, H. R. Culling, W. D. Moore, N. K. B. Patch, S. B. Cuthbert.

Organization of New Board

The Chair announced that the first order of business would be the organization of the new Board, that the By-Laws provided for election by the Board of an Executive Secretary, Treasurer, Technical Secretary, Assistant Secretary and Manager of Exhibits, and that at the discretion of the Board any of the above-named offices could be combined.

On motion duly seconded, the offices of Executive Secretary, Treasurer and Manager of Exhibits were combined.

The Chair named a Nominating Committee to nominate officers and four members of the Board to serve as members of the Executive Committee together with the President, Vice-President and Executive Secretary. The committee submitted the following nominations:

For the office of Executive Secretary, Treasurer, and Manager of Exhibits—C. E. Hoyt.

For the office of Technical Secretary—R. E. Kennedy.

For the office of Assistant Secretary-Treasurer—Jennie Reininga.

For members of the Executive Committee—D. M. Avey, E. H. Ballard, H. Bornstein, and Fred L. Wolf.

There being no further nominations, the Chair declared the nominations closed, whereupon it was moved and seconded that the unanimous ballot of the Directors be cast for the nominees submitted by the Nominating Committee. Motion prevailed.

Provision for Election of 1932-33 Nominating Committee

On motion duly seconded, the President was authorized to appoint a committee of three to present to the Board, for approval by letter ballot, a list of members whose names should appear on the ballot for the election by the members of four members of the Nominating Committee to serve with the three last living past-presidents, in accordance with the provisions of the By-Laws.

Finance Committee

On motion duly seconded, President T. S. Hammond, Vice-President Frank J. Lanahan and past-President E. H. Ballard were elected members of the Finance Committee, with past-President Ballard as Chairman.

Committee on Research Appropriations

On motion duly seconded, the President was authorized to appoint a committee of four on research appropriations.

Disbursement of Funds Resolutions

On motion duly seconded, the following resolutions were unanimously adopted:

Resolved, that resolutions required by the banks in which the funds of the Association are deposited, authorizing the withdrawal of all securities in the Sinking Fund of the Department of Exhibits of the American Foundrymen's Association, held by the Trust Department of the Harris Trust & Savings Bank, and the withdrawal of all funds in all interest savings accounts of the Association shall require two signatures, as follows:

The President and the Executive Secretary-Treasurer.

The Vice-President and the Executive Secretary-Treasurer, or

The President and the Vice-President.

Resolved, that the Board authorize a Secretary-Manager's petty cash fund of \$1000.00, said fund to be reconciled at the end of each month by a full statement of expenditures, withdrawal checks to be signed by the Executive Secretary-Treasurer or the Assistant Secretary-Treasurer.

Salaries and Compensations

Executive Secretary C. E. Hoyt, commenting on the reports of the Treasurer submitted at the opening meeting of this Convention and at the meeting of the retiring Board of Directors just held, stated that he had met with members of the Finance Committee during the day and discussed with them the 1932-33 budget, and that at this conference he had recommended further salary revisions downward.

Mr. Hoyt then stated he would recommend that in lieu of voting salaries at this meeting, the Board authorize the Finance Committee to determine from time to time what salaries and compensations should be paid officers and clerical help during the fiscal year beginning July 1, 1932. On motion duly seconded, such authorization was given the Finance Committee.

Treasurer's and Assistant's Bonds

On motion duly seconded, bonds for the Treasurer and Assistant Treasurer were fixed at \$5000.00, premiums thereon to be paid by the Association.

Appropriations for Prizes

On motion duly seconded, the Board of Directors authorized the offering of prizes for apprentice molding and pattern making contests at the 1933 convention, provided the Board of Awards voted the necessary funds for said prizes.

Resolution Authorizing Committee Meeting Expenses

On motion duly seconded, the following resolution was adopted:

Resolved, that the Treasurer be authorized to reimburse the traveling expenses of Directors and committee members for attendance at any regularly called Board or committee meetings, with the following exceptions:

(1) When meetings are held in conjunction with other committees or associations, the Treasurer is authorized to determine what portion of the expense of attending such meetings shall be paid by the Association.

(2) No expenses shall be paid to Directors or committee members for attendance at meetings held during the week of the annual convention of the Association, unless specially authorized.

Committee Appointments

On motion duly seconded, the President was authorized to make all appointments for standing and special committees not provided for in the By-Laws or by special act of the Board.

Report of Committee on International Relations

D. M. Avey, Chairman of the Committee on International Relations, reported that at a meeting held the previous day it was voted to recommend to the Board of Directors that they announce to members and to the Association Technique de Fonderie de France, hosts for the 1932 International Foundry Congress, that because of industrial conditions in the United States it does not seem advisable to attempt to organize an official party to represent the A.F.A.

It was further recommended that the headquarters of the Association act as a clearing house in assisting individuals who desire to attend the International Congress, and in every way to endeavor to further the success of the Paris convention.

Appointment of Committee on Handbook Policy

The report of recommendations of the Divisional Activities Correlation Committee, submitted at the previous Board meeting and referred to the new Board, was discussed at length. It then was moved that the President be authorized to appoint a small committee to review the status of the Cast Metals Handbook project and recommend a program for preparing and issuing such a handbook by the A.F.A. covering all classes of cast metals.

Appropriation for Handbook

The Executive Secretary recommended that what is known as the Philadelphia Research Fund, totaling \$2029.42 on March 31, 1932, be made available at the discretion of the Finance Committee toward defraying the cost of publishing a Handbook on Cast Metals. On motion, the recommendation was approved.

Report on Health Protection in Sandblasting

The Secretary reported that the officers of A.F.A. called a meeting in Chicago March 8, 1932, to consider a report of the committee of the National Safety Council and the U. S. Department of Health on "Health Protection in Sandblasting and Metallic Abrasive Blasting," and that at that meeting the following were named as a committee to appear before the Executive Committee of the National Safety Council in New York on March 14 to protest the publication of this report until representatives of the foundry industry had been given an opportunity to consider the report and submit recommendations for its revision:

- E. O. Jones, Safety Engineer, Belle City Malleable Iron Co.,
Racine, Wis.
- S. C. Vessy, President, W. W. Sly Mfg. Co., Cleveland.
- L. M. Hansen, Consulting Engineer, Chicago.

This committee, supported by more than 300 telegrams and letters addressed to the President of the National Safety Council, attended the meeting at New York and were successful in securing an extension of time.

On March 29 a second meeting was held in Chicago, at which time the report of the committee of three was received, whereupon it was voted to create a steering committee consisting of one representative from each of the following associations:

- American Foundrymen's Association
- National Founders' Association
- Malleable Iron Research Institute
- Steel Founders' Society of America
- Gray Iron Institute
- Foundry Equipment Manufacturers' Association

This committee named the following as a committee to review the report in question and prepare a report to be submitted to a special reviewing committee of three named by the president of the National Safety Council.

- E. O. Jones, Safety Engineer, Belle City Malleable Iron Co.,
Racine, Wis.
F. H. Elam, Casualty Department, American Steel Foundries,
Chicago.
Dr. Joseph H. Chivers, Crane Company, Chicago.
C. E. Hoyt, Executive Secretary, American Foundrymen's
Association, Chicago.

The Secretary stated that this committee was conducting negotiations with the officers of the National Safety Council and it was hoped that the outcome would be acceptable and fair to the members of the foundry industry.

Reports of Special Committees

D. M. Avey, member of the Committee to Cooperate with the New York Museum of Science and Industry, submitted a brief report of the work of the committee and the exhibit which had been assembled, stating that in the opinion of the committee the exhibit was far from complete but that a good start had been made.

David Evans, Chairman of the Committee to Cooperate with the Rosenwald Museum of Science and Industry in Chicago, reported that meetings of the committee had been held, that plans were under way, and urged all present to respond to appeals which would be made in the near future for assistance in assembling a representative exhibit for the foundry industry.

Election to Life Membership

On the recommendation of the Executive Secretary, C. H. Gale, who retired in 1922 after forty-eight consecutive years of service in the foundry industry and who had continued his active membership in the Association to date, was elected to Life Membership.

1933 Annual Meeting

On motion duly seconded, the President was authorized to appoint a committee to consider plans for the 1933 annual meeting and submit recommendations to the Board of Directors for approval by letter ballot.

Registration Fee

The Secretary requested an expression from the Directors and others present on the policy of a universal registration fee, which had been inaugurated for the 1932 convention. All expressions were in favor of continuing the policy, and on motion duly seconded it was unanimously voted to charge a registration fee of \$1.00 at the 1933 annual meeting.

There being no further business, the President called for remarks from past presidents and past directors, and on motion duly seconded the meeting stood adjourned.

Respectfully submitted,

C. E. HOYT, *Executive Secretary.*

Minutes of Executive Committee Meeting 1932-33 Board of Directors

AMERICAN FOUNDRYMEN'S ASSOCIATION
WALDORF-ASTORIA HOTEL, NEW YORK, NOV. 17, 1932

President T. S. Hammond, presiding.

Roll Call

A special meeting of the Executive Committee was called by President Hammond, to convene following adjournment of the annual meeting of the National Founders' Association, the following members of the Executive Committee responding to roll call: President T. S. Hammond; Vice-President Frank J. Lanahan; E. H. Ballard, Dan M. Avey, C. E. Hoyt. Absent, H. Bornstein, Fred L. Wolf.

Treasurer's Report

The Treasurer submitted a report showing a comparative statement of income and expense for the period July 1-November 1, 1931, and for the same period in 1932. The statement showed that receipts from dues for the first four months this year were \$6690.72 less than for the same period last year, and total receipts \$6609.54 less. The statement also showed that total expenses for the same period were \$5742.43 less in 1932 than in 1931, and that the excess of income over expense for the first four months of 1932 was \$867.11 less than in 1931. The Treasurer reported that salaries and stenographic costs were 38.5 per cent less for this period than for the same period in 1931.

Membership Report

The Secretary reported that the paid-up membership on November 1, 1932, was 424 less in all classes than at the same time in 1931, divided as follows: Firm memberships 89, Individual memberships 178, Affiliated memberships 163, and an increase of 6 in Associate memberships.

Cast Metals Handbook

The Secretary reported progress in accumulating and editing material for the Cast Metals Handbook and submitted a tentative program for inclusion of advertising pages in the Handbook. This material was typed and, to save time, the members were requested to take it home for study and then to submit their reactions.

As a matter of record, the Secretary was authorized to show in the minutes of this meeting that the Finance Committee had, by letter ballot, voted to make available the Philadelphia Research Fund toward defraying the cost of the Cast Metals Handbook, as authorized by action of the Board of Directors at the annual meeting held in Detroit, May 5, 1932.

Health Protection in Sandblasting

It was moved, seconded and carried that the Executive Committee approve the acts of officers and representatives of A.F.A. in protesting publication of a report entitled "Health Protection in Sandblasting and Metallic Abrasive Blasting."

On motion duly seconded, it was voted to approve the action of the officers in entering into an agreement with the Industrial Health Conservancy Laboratories for services on a retainer basis at \$200.00 per annum, beginning Sept. 1, 1932.

Endorsement of A.S.T.M. Standards

Vice-President Frank J. Lanahan, Chairman of the Divisional Activities Correlation Committee, reported that a communication had been received from C. L. Warwick, Secretary of American Society for Testing Materials, outlining a plan whereby reprints of A.S.T.M. specifications in the future would carry a notice of the various organizations endorsing each specification, and inviting the A.F.A. to approve this plan. Mr. Lanahan further reported that the proposal had been referred to the Divisional Activities Correlation Committee for recommended action to the Board, and that unanimous approval of this plan had been obtained from members of the committee.

Mr. Lanahan then moved that the Executive Committee recommend to the Board, for approval by letter ballot, the following procedure:

- (1) That each Division, through its Specifications Committee, review A.S.T.M. specifications.
- (2) Those that are found satisfactory shall be recommended to the Divisional Advisory Committee for A.F.A. endorsement.
- (3) When the Divisional Advisory Committee has, by letter ballot, approved any specifications, they shall be submitted to the A.F.A. Board of Directors for approval.
- (4) When specifications have been approved by the Board, the A.S.T.M. shall be given authorization to print on said specifications that they have been endorsed by the A.F.A.

Motion seconded and carried.

A.S.M.E. Foundry Practice Division

A report was received from Technical Secretary R. E. Kennedy on the program of the Foundry Practice Group under the Machine Shop Practice Division of the A.S.M.E., stating that at the December annual meeting of the A.S.M.E. the following papers, supplemented by written discussion, would be presented:

"Malleable Iron as a Component Part of Machines and Structures," by E. Touceda, Albany, N. Y.

"Special Steels for Castings," by R. A. Bull, Director, Electric Steel Founders' Research Group, Chicago.

Apprentice Molding and Pattern Making Contests

On motion duly seconded, it was voted to recommend to the Committee on Apprentice Training and to the Board of Awards, who provide

the funds for apprentice contest prizes, that there be no apprentice molding and pattern making contests staged at the 1933 Convention.

1933 Nominating Committee

President Hammond announced that he would appoint the members of the Executive Committee as a committee to propose names of members to appear on the letter ballot for the election of four members of the 1933 Nominating Committee, their recommendations to be approved by letter ballot of the Board of Directors.

1934 Nominating Committee

Consideration was given the method of election of four members of the Nominating Committee, and it was voted to recommend to the Board of Directors that four members of the 1934 Nominating Committee, as provided for in Article IX, Section 1 of the By-Laws, be elected by the members at the 1933 annual meeting of the Association.

1933 Convention and Exposition

The Secretary reported that following an unanimous letter-ballot authorization by the directors, he had made formal arrangements for staging the 1933 Convention and Foundry and Industrial Exposition of the Association at the Stevens Hotel, Chicago, the week of June 19, that a schedule of meeting-room accommodations had been filed and accepted by the hotel, and that the Exhibition Hall had been reserved for exhibits on the same terms as applied in 1929 and 1931.

On motion duly seconded, it was voted that the minimum rate for exhibition space be \$1.00 per square foot and the maximum \$1.25, with the maximum rate applying to preferred corner locations, and that the standard Rules and Regulations for the conduct of expositions in conjunction with the annual conventions be approved.

In view of the great interest in the Century of Progress, it was voted to recommend to the Program Committee that they arrange for a limited number of sessions and limited number of papers and discussions at each session. It was further recommended that no provision be made for evening meetings or entertainment, including the customary banquet and the usual exhibitors' dinner.

It was voted to authorize that an official invitation be extended the Materials Handling Division of the A.S.M.E., the Materials Handling Institute and the American Gas Association to participate in the 1933 Annual Convention and Industrial Exposition of the Association.

By invitation, past-President S. W. Utley was in attendance at this meeting and participated in the deliberations of the Executive Committee.

Respectfully submitted,

C. E. Hoyt, *Executive Secretary.*

Contribution to Study of Martensitic Quenching of Alloy Cast Irons^{*}

BY MARCEL BALLAY,† PARIS, FRANCE

Abstract

Mechanical properties of cast iron are closely allied to quantity, distribution and form of the graphite. When everything possible has been done as concerns graphite, it then is necessary to look to improvement of the pearlite, which leads to the question of heat treatment. For many industrial applications it is essential to have an iron very hard but still machinable, and the martensitic quench is a logical way of getting such an iron. Various solutions are available for obtaining hard, machinable cast irons, such as (1) irons relatively soft as cast, hardened by quenching and drawn, (2) a more complex heat treatment, comparable to that for self-hardening steels, (3) a simple draw of the pieces as cast having a suitable composition, and (4) a partial quench during cooling in the mold. Hardness must be obtained without excess cementite, for ready machinability. Silicon and chromium increase the final transformation temperature in heating, and consequently the quenching temperature; nickel and manganese lower the transformation temperature. Phosphorus and carbon have little influence from this point of view. Nickel is the only graphitizing element that lowers the temperature of the martensitic quench. The influence of these various elements are illustrated in the paper by dilatometric determinations and by curves indicating the influence of quenching temperature on hardness of cast irons. Silicon increases the critical quenching rate, while nickel, manganese and chromium act oppositely. Curves are given to illustrate the hardness in relation to cooling speed for cast irons of different compositions. To avoid quenching cracks it is advisable to utilize irons quenched at low temperatures and to employ as slow a cooling rate as possible, by decreasing silicon content and adding nickel. Up

^{*} Exchange paper presented on behalf of Association Technique de Fonderie de France, the French Technical Foundry Association.

† Director of Metallurgical Investigations, French National Aeronautical College.

to one per cent manganese also is recommended, while chromium permits increased hardness with the same drawing temperature. Quenching and drawing improve the mechanical properties of cast iron. A draw at a low temperature is particularly advisable, since it decreases brittleness and increases compression, shearing and transverse strength figures without materially reducing the hardness.

1. Knowledge of the relations existing between structure, constitution and properties of cast irons is increasing daily, bringing about constant improvement in the quality of castings. In spite of this fact, the mechanical properties of cast iron remain rather mediocre as compared with those of steel.

2. It has been suggested in the past that cast iron eventually would be almost eliminated by steel, but certainly there is nothing to be feared in this direction. Simplicity in production of cast iron, the facility with which sound castings are obtained, its machinability and low price, assure cast iron of numerous applications which it can hold without fear of competition. It is necessary to add to these favorable circumstances certain other interesting properties such as excellent resistance to wear, which appears to be allied to the presence of graphite.

3. It has long been known that good cast iron must consist of pearlite and graphite, with as little ferrite or free cementite as possible. Mechanical properties of pearlitic irons are particularly dependent upon the quantity, distribution and form of the graphite, which explains the tendency and interest shown toward irons of low carbon content. When all methods in this direction have been exhausted, it becomes necessary to see how one can modify the pearlite, high-quality irons being actually not pearlitic but sorbitic, it being understood that these irons do not possess worth-while properties unless their graphite presents suitable characteristics.

4. High hardness is essential for numerous types of engineering castings which must be machined. In ordinary irons increased hardness is in relation to the increase of percentage of combined carbon or cementite, and little can be done in this direction. An ordinary iron of 270 Brinell hardness is extremely difficult to machine by the usual methods, but it is possible to go much farther with alloy irons, with or without heat treatment. The example below seems to the author to be typical of this relation between hardness and machinability.

Example of Effect of Heat Treatment

5. An iron melted in the crucible and cast in dry sand in test bars of 25-mm. diameter, showed the following analysis: Total carbon 2.65 per cent, silicon 1.35, manganese 0.95, nickel 2.60, chromium 0.75, sulphur 0.04, and phosphorus 0.07. This iron was almost completely white as cast, with Brinell hardness of 500 (Fig. 1-A). It then was heated to 1000 degs. Cent. (1832 degs. Fahr.) during $3\frac{1}{2}$ hours and cooled in the furnace from 980 degs. Cent. to 520 degs. Cent. (1796 to 968 degs. Fahr.) in 20 minutes.

6. After this graphitizing treatment the iron had the appearance shown in Figs. 1-B and 1-C. Its Brinell was 360 (3000 kg. with a 10-mm. ball), but the iron machined without much difficulty by hand and machine sawing, turning, milling and drilling. It is interesting to note the form and dimensions of the graphite, for the author has never encountered an iron of equal hardness which contained graphite flakes but still was machinable.

Machinable Castings of High Hardness

7. Several possible methods of obtaining machinable castings of high hardness are as follows:

(a) One can start with an iron machinable as cast, which, after machining, is hardened by quenching—followed or not by

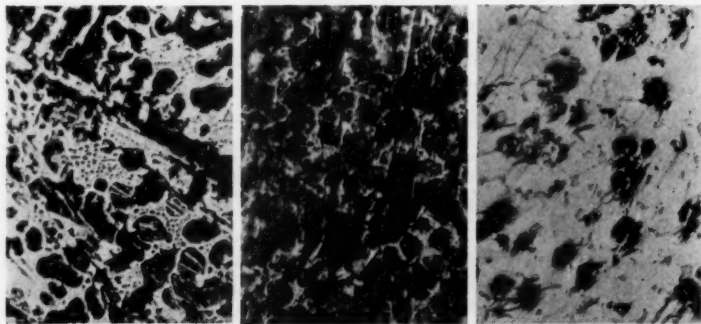


FIG. 1—CRUCIBLE-MELTED IRON, CAST IN DRY SAND MOLDS. ANALYSIS: TC 2.65 PER CENT; MN 1.0; SI 1.35; P 0.07; S 0.04; NI 2.60; CR 0.75. A (LEFT): AS CAST; BRINELL HARDNESS 500; ETCHED IN 4 PER CENT NITRIC ACID, X80. B (CENTER): ANNEALED AT 1000 DEGS. CENT. (1832 DEGS. FAHR.) FOR $2\frac{1}{2}$ HOURS; BRINELL HARDNESS 360; ETCHED IN 4 PER CENT NITRIC ACID, X80. C (RIGHT): SAME AS B BUT NOT ETCHED; X80.

drawing. The characteristics of such an iron will be taken up later in detail; it need only be noted here that, on account of the low resistance of the iron to deformation, the rate of cooling must be relatively slow. Oil quenching can be employed only in certain special cases, it being necessary usually to be content with an air quench to avoid cracking.

(b) For castings of more complex design, it is impossible to quench in oil or even in still air, and thus it is necessary to resort to irons with a very low critical rate of quenching, comparable to that for self-hardening steels. The castings will be hard as cast and the heat treatment more intricate, including:

- (1) Softening by drawing to permit machining.
- (2) Machining.
- (3) Heating and cooling relatively slowly.
- (4) Drawing to a greater or lesser degree, followed in some instances by finishing by grinding.

(c) With these irons a simple draw of the pieces as cast is sometimes sufficient, giving a fairly high hardness but permitting machining. This is possible only with alloy irons containing no excess of cementite.

(d) By regulating the analysis of the iron employed for the melt, it is possible to obtain a sorbite relatively hard as cast but which can be machined without difficulty. In this manner hardnesses up to 300 Brinell can be obtained, but the method is somewhat uncertain since very small variations in analysis will produce castings either too high or too low in hardness.

(e) Various other methods can be suggested but apparently have no practical application. One can readily understand the utility of austenitic irons as cast and hardened by subsequent drawing, which may lead either to a martensitic structure or to precipitation of compounds whose solubility varies with the temperature (for example, those of titanium, molybdenum and aluminum). In every test made in this direction the author always has encountered difficulties, in that the unstable austenites which could be hardened by drawing are extremely difficult to machine despite their relatively low hardness.

Influence of Various Elements on Martensitic Quench

8. Due to the complexity of cast iron, it is difficult to describe in detail the influence on a martensitic quench of the

Table 1

Sample No.	CHEMICAL COMPOSITION								TRANSFORMATION TEMPERATURE RANGE									
									On Heating					On Cooling				
	TC	Mn	Si	Ni	Cr	P			Ac		Ar ¹		Ar ²		Ar ³		Ar ⁴	
									Beginning.	End.	Beginning.	End.	Beginning.	End.	Beginning.	End.	Beginning.	End.
	Degs. Cent.	Degs. Fahr.	Degs. Cent.	Degs. Fahr.	Degs. Cent.	Degs. Fahr.	Degs. Cent.	Degs. Fahr.	Degs. Cent.	Degs. Fahr.	Degs. Cent.	Degs. Fahr.	Degs. Cent.	Degs. Fahr.	Degs. Cent.	Degs. Fahr.	Degs. Cent.	Degs. Fahr.
75	3.38	0.37	2.00	....	....	0.37	....	....	755	1391	800	1472	710	1310	660	1220	....	....
76	3.12	0.60	1.46	1.15	....	0.39	....	....	725	1337	770	1418	685	1265	635	1175	....	....
105	3.42	1.10	1.80	3.32	....	0.14	....	....	680	1256	740	1364	610	1130	530	986	....	....
115	3.08	0.92	1.57	4.02	....	0.08	....	....	635	1175	710	1310	550*	1022*	....	....	....	....
116	3.07	0.91	1.70	5.07	....	0.08	....	....	635	1175	710	1310	....	....	....	....	....	....
428	2.68	1.01	1.38	2.60	....	0.07	....	....	685	1265	745	1373	635	1175	590	1094	....	....
430	2.58	0.90	3.02	2.74	0.74	0.07	....	....	745	1373	802	1476	697	1287	647	1197	....	....
432	2.65	0.86	2.06	2.72	....	0.07	....	....	690	1274	765	1409	635	1175	590	1094	....	....
433	2.70	0.86	2.16	2.67	0.74	0.07	....	....	720	1328	780	1436	630	1166	590	1094	....	....
434	2.72	0.83	3.00	2.87	0.74	0.07	....	....	740	1364	800	1472	697	1287	647	1197	....	....
444	3.39	0.95	1.41	3.00	....	0.05	....	....	680	1256	745	1373	630	1148	550	1022	....	....
445	2.48	0.83	1.35	2.98	....	0.05	....	....	680	1256	747	1379	630	1166	588	1090	....	....

* Approximate.

† Indefinite.

Avg. heating rate on rising from 20 degs. to 850 degs. Cent. (68 degs. to 1562 degs. Fahr.)=20 degs. Cent. (36 degs. Fahr.) per minute.

Ave. cooling rate on cooling from 850 degs. to 500 degs. Cent. (1562 degs. to 932 degs. Fahr.)=14 degs. Cent. (25 degs. Fahr.) per minute.

Maximum temperature attained=850 degs. Cent. (1562 degs. Fahr.)

Sulphur content is about 0.05 per cent for all samples.

various chemical elements in the composition of cast irons—carbon, silicon, manganese, sulphur, phosphorus, nickel and chromium. By referring only to machinable irons (which must contain only a very small quantity of free cementite), the problem is somewhat simplified, as the necessity for ready machinability limits the amounts of elements stabilizing the cementite, manganese and chromium. It is of particular interest to note that nickel is the only graphitizing element having a favorable action on the martensitic quench, explaining its presence in most irons studied by the author.

Action on Temperature of Martensitic Quenching

9. The data of Table 1 have been determined by means of a Chevenard photographic dilatometer and are largely taken from recent studies.¹ Figures cited have been selected as examples of the influence of various elements.

10. Silicon raises considerably the position of the critical range in the temperature scale. Silicon of 1 per cent raises the temperature of the end of the transformation on heating from 20 to 40 degs. Cent. (36 to 72 degs. Fahr.), according to the composition of the iron (Nos. 433 and 434 in accompanying tables).

11. Chromium acts in the same manner (Nos. 432 and 433). In an iron containing 5 per cent nickel and 3 per cent silicon, 1 per cent chromium raises the temperature of the end of the transformation nearly 40 degs. Cent. (72 degs. Fahr.).

12. Nickel, on the contrary, has a pronounced lowering effect on the critical range. With irons containing 4 to 5 per cent nickel, the transformation on heating ends at 710 degs. Cent.—1310 degs. Fahr. (Nos. 115 and 116). The comparison of samples Nos. 75 and 76 is interesting, since in the latter, part of the silicon content has been substituted by nickel, which results in lowering the temperature of the end of the transformation on heating by 30 degs. Cent. (54 degs. Fahr.)

13. Manganese acts similarly to nickel but apparently more actively on irons of low silicon content than on those of higher silicon. The action of 0.2 to 1 per cent manganese is very striking, but in practically all cases there appears to be little value in exceeding 1 per cent, particularly for castings of thin sections.

¹ Guillet, Galibourg and Ballay, "Recherches sur la Trempe Martensitique et le Traitement Thermique Durcissant des Fontes," *Revue du Metallurgie*, 1931, vol. 28, pp. 581-597.

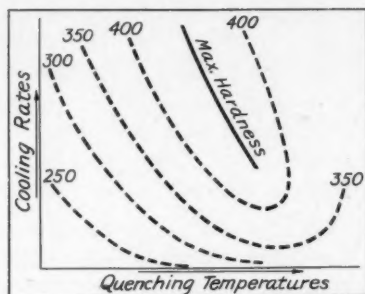


FIG. 2—CURVES OF EQUAL HARDNESS FOR DIFFERENT QUENCHING TEMPERATURES AND RATES OF COOLING.

14. Phosphorus has no appreciable action on the transformation points, at least between 0.1 and 0.8 per cent, while to our knowledge no systematic tests have been made on the influence of sulphur.

15. Total carbon does not influence the position of the transformation points on heating (Nos. 444 and 445), but it appears to have some effect on the points on cooling.

Critical Quenching Speed

16. Several criterions can be taken for increasing the effectiveness of a quench, the hardness being of the most interest to the foundryman. A complete understanding of the properties

Table 2

INFLUENCE OF DIFFERENT QUENCHING TEMPERATURES AND RATES OF COOLING ON CAST IRON

Brinell Hardness (750 kg. with 5-mm. ball), after heating to 825 degs. Cent. (1517 degs. Fahr.) for 5 min. and cooling as shown

Sample No.	Oil,	Air,	Box,	Furnace,	Furnace,
	54 degs. Cent. per sec.	200 degs. Cent. per min.	28 degs. Cent. per min.	5.4 degs. Cent. per min.	1 deg. Cent. per min.
432	475	450	232	195	150
433	490	403	276	255	237
434	483	303	273	253	220
444	409	393	215	163	170
445	450	403	249	210	187
105	361	379	204	181	158
115	366	343	309	262	192
116	348	366	326	339	240
471	357	343	291	309	255
474	352	379	370	352	282

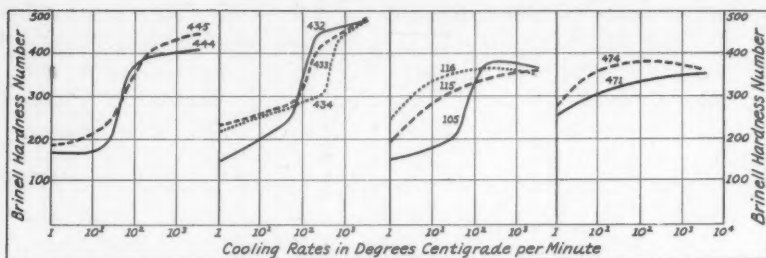


FIG. 3—HARDNESS RESULTS OF SEVERAL SPECIMENS WHEN COOLED AT VARYING RATES.

of an iron from this point of view necessitates determination of a set of curves of equal hardness for different quenching temperatures and rates of cooling. Such curves are shown in Fig. 2, and data are given in Table 2 illustrating the influence of the rate of cooling on hardness of irons heated to 825 degs. Cent. (1517 degs. Fahr.) and maintained at this temperature for 5 minutes. The test pieces were disks 25 mm. (0.98 in.) in diameter and 6 mm. (0.24 in.) thick, cooled at the following rates when cooling from 825 degs. Cent. to 500 degs. Cent. (1517 degs. Fahr. to 932 degs. Fahr.):

(a) 1 deg. Cent. (1.8 degs. Fahr.) per minute in an electric furnace, suitably regulating current during cooling.

(b) 5.4 degs. Cent. (9.7 degs. Fahr.) per minute in an electric furnace, current being cut off at start of cooling.

Table 3

INFLUENCE OF SILICON ON QUENCHING IRONS OF FAIRLY HIGH NICKEL CONTENT

Sample No.	Ni	Cr	Si	As Cast.	Brinell Hardness (3000 kg. with 10-mm. ball)	
					Drawn at 700° C. (1292° F.) 30 min.	Drawn at 700° C. (1292° F.) 2 hrs. 30 min.
470	4.66	....	1.33	269	354	315
472	4.66	....	3.38	337	215	191
473	4.85	1.16	1.55	293	360	427
475	4.85	1.16	3.48	342	273	253

(c) 28 degs. Cent. (50 degs. Fahr.) per minute in a box filled with sand.

(d) 200 degs. Cent. (392 degs. Fahr.) per minute chilled in air.

(e) 54 degs. Cent. (97 degs. Fahr.) per second quenched in oil (this figure is only approximate, possibly having an error of about 20 per cent).

17. Compositions of irons Nos. 432, 433, 434, 105, 115 and 116 are given in Table 1. Irons No. 471 and 474 contain 4.8 per cent nickel; No. 474 contains, in addition, 1 per cent chromium. The results have been plotted in Fig. 3, for which we have taken as abscissas the logarithms of cooling rates in degrees Centigrade per minute during cooling from 825 degs. Cent. to 500 degs. Cent. (1517 degs. Fahr. to 932 degs. Fahr.)

18. A number of interesting conclusions can be drawn from studies made on the critical rate of cooling. Silicon increases this critical rate; that is, the higher the silicon, the more rapid must be the cooling to obtain martensite in low alloy irons. Its influence on quenching irons containing a rather high nickel content is illustrated by the data of Table 3.

19. Table 3 refers to two series of irons with essentially the same carbon and manganese contents, the chemical analysis of each series having been kept strictly alike with the exception of the silicon, and the same melt used with an addition of some 98 per cent silicon in the second iron of each series. Nos. 470 and 472 contain no chromium, while Nos. 473 and 475 contain 1.16 per cent chromium.

20. As cast, irons Nos. 470 and 473 are much less hard than Nos. 472 and 475, since they are partially over-quenched. The presence of austenite is readily detected by a magnet, iron No. 473 in particular being almost non-magnetic. Figs. 4-A and 4-B show the structure of irons Nos. 470 and 472 as cast, austenite being visible on the first of these micrographs. The second iron is martensitic.

21. Drawing at 700 degs. Cent. (1292 degs. Fahr.) transformed this austenite into martensite. Considerable increase in hardness was noted with irons Nos. 470 and 473 by drawing at 700 degs. Cent. (1292 degs. Fahr.), while for Nos. 472 and 475, martensitic as cast, drawing led to very marked softening. This

decrease in hardness is less for iron No. 475 containing chromium than for iron No. 472 which has none. In spite of its relatively low hardness as cast, iron No. 470 is practically unmachinable by the usual methods, and it was necessary to employ tungsten-carbide tools. The same was true for iron No. 473, which was almost entirely austenitic.

22. Chromium, manganese and nickel decrease the critical quenching speed and permit the formation of martensite with slow cooling. The fact that the chromium and manganese contents must be maintained sufficiently low to avoid an excess of cementite has already been discussed.

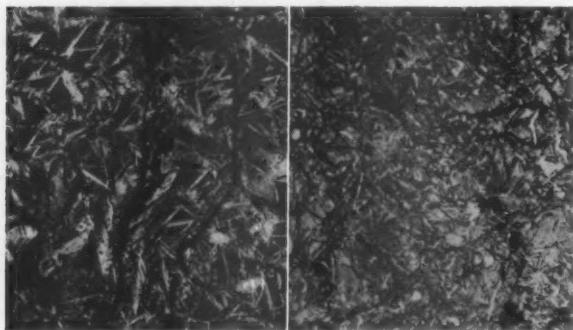


FIG. 4—A (LEFT): IRON No. 470 AS CAST (Ni 4.66 PER CENT; Si 1.33); SHOWING AUSTENITIC STRUCTURE; X200. B (RIGHT): IRON No. 472 AS CAST (Ni 4.66 PER CENT; Si 3.38); ETCHED IN 4 PER CENT NITRIC ACID, SHOWING MARTENSITIC STRUCTURE; X200.

23. Phosphorus in quantities of 0.1 to 0.8 per cent has little or no action on the critical rate of quenching, while little is known of the influence of sulphur.

24. Total carbon also has no appreciable influence, as is indicated by the curves of Fig. 3, referring to samples Nos. 444 and 445. The importance of combined carbon, which is a function of the chemical composition and thermal history, is difficult to determine and has never been clearly established. It appears to be relatively minor if a specific action on the quenching speed is attributed to silicon. In any event, this point is not of material practical importance, since the combined carbon often is a relatively uncertain quantity, being the difference between the total

and graphitic carbon contents, in determination of which errors both ways may enter.

25. It is interesting to note the difference in appearance of the curves $\Delta = f(V)$ indicating the influence of the cooling speed on the hardness in irons having low alloy contents and in self-hardening irons. For these (see irons Nos. 115 and 116 in Fig. 3, for instance) the variation in hardness is very regular and does not present sharp differences as is the case with iron No. 105.

26. Fig. 5 illustrates the variation in hardness with the quenching temperature for an ordinary iron and for three irons of increasing nickel contents, the irons being quenched in oil. It

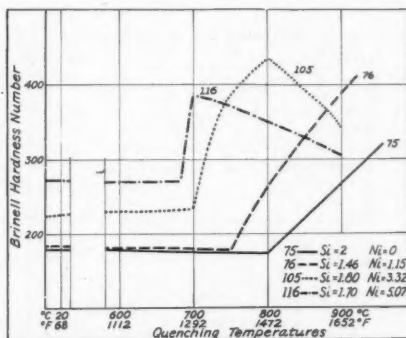


FIG. 5—QUENCHING TEMPERATURES AS AFFECTING BRINELL HARDNESS OF FOUR CAST IRONS. SPECIMEN NO. 75, ORDINARY IRON; SPECIMENS 76, 105 AND 116, NICKEL CAST IRONS.

will be noted that the 5 per cent nickel iron was hardened considerably by an oil quench after heating to 700 degs. Cent. (1292 degs. Fahr.)

SELECTION OF ANALYSIS FOR HEAT TREATMENT

27. The necessity of avoiding quenching cracks most frequently regulates the rate of cooling and the composition of the iron. For castings of simple shape it is possible to employ ordinary irons having fairly high percentages of manganese or chromium and manganese, as indicated by Hurst. The addition of nickel permits lowering of the quenching temperature.

28. For castings of more complex design and varying sections

an oil quench often is impossible, and usually it is necessary to quench by cooling in calm air or even by a retarded cooling, leaving the castings in the furnace or in an enclosed space where the rate may be regulated. It is advantageous to employ an iron which can be quenched at as low a temperature as possible; additions of nickel facilitate this. In most cases the manganese content can be 1 per cent and nickel content between 2 and 6 per cent, silicon being maintained at a percentage sufficient to obtain a casting completely gray.

29. In the case of well-known compositions for obtaining ordinary irons completely gray, certain definite changes must be made in the composition to obtain an iron susceptible to heat

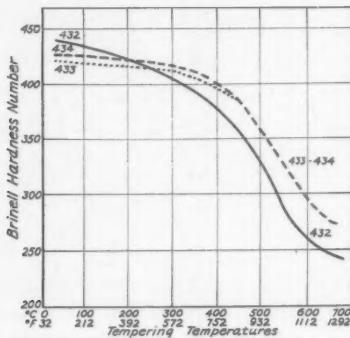


FIG. 6—EFFECT OF VARYING TEMPERING TEMPERATURES ON BRINELL HARDNESS.

treatment. The simplest solution is to substitute nickel for silicon, keeping the latter above 1 per cent. Tables and curves in this paper permit an estimation of suitable manganese, nickel and chromium contents.

30. The influence of chromium on hardness after drawing is clearly indicated by the curves of Fig. 6. Chromium gives an increase of hardness for the same drawing temperature after quenching. To obtain high hardnesses after quenching and drawing, it is best to employ irons containing low total carbon and some chromium, it being evident that an increase in graphite tends to lower the hardness.

31. It should be remembered that, in quenching irons of low critical quenching rate at too high a temperature, austenite

Table 4

EFFECT OF QUENCHING AND DRAWING ON HARDNESS, COMPRESSION, SHEAR AND TRANSVERSE STRENGTH OF IRON "A"

CHEMICAL ANALYSIS:

TC	3.35	Ni	1.82
Mn	1.13	P	0.73
Si	1.72	S	0.06

BRINELL HARDNESS:

As cast	170
Oil quenched at 810 degs. Cent. (1492 degs. Fahr.)	353
Oil quenched at 810 degs. Cent. (1492 degs. Fahr.) and drawn at 300 degs. Cent. (572 degs. Fahr.)	347

COMPRESSION STRENGTH:

	Kg. per sq. mm.	Lbs. per sq. in.
As cast	80	121,000
Oil quenched at 810 degs. Cent. (1492 degs. Fahr.)	75.3	107,000
Oil quenched at 810 degs. Cent. (1492 degs. Fahr.) and drawn at 300 degs. Cent. (572 degs. Fahr.)	115	163,200

SHEAR STRENGTH:

	Kg. per sq. mm.	Lbs. per sq. in.
As cast	25.5	36,260
Oil quenched at 810 degs. Cent. (1492 degs. Fahr.)	20.2	28,730
Oil quenched at 810 degs. Cent. (1492 degs. Fahr.) and drawn at 300 degs. Cent. (572 degs. Fahr.)	30.2	43,200

TRANSVERSE STRENGTH—with test piece $8 \times 10 \times 35$
mm. ($0.315 \times 0.394 \times 1.378$ in.) supported at points
30 mm. (1.18 in.) apart:

	Kg. per sq. mm.	Lbs. per sq. in.
As cast	515	1136
Oil quenched at 810 degs. Cent. (1492 degs. Fahr.)	245	540
Oil quenched at 810 degs. Cent. (1492 degs. Fahr.) and drawn at 300 degs. Cent. (572 degs. Fahr.)	510	1125

is obtained and a relatively low hardness figure results. To compare irons of different compositions as regards hardness, it is necessary to quench not at the same temperature but at a certain number of degrees above their transformation point on heating.

PROPERTIES AND APPLICATIONS OF HEAT-TREATED IRONS

32. Results proven in practice with heat-treated irons show that the increase in hardness affects the resistance to wear very favorably. It always is advisable to follow the martensitic quench by drawing at a temperature of at least 200 to 300 degs. Cent. (392 to 572 degs. Fahr.), as this appears to reduce internal stresses. The draw produces a marked increase in compression strength and in shear and bend tests, as compared with the "as cast" state,

Table 5

EFFECT OF QUENCHING AND DRAWING ON HARDNESS, COMPRESSION, SHEAR AND TRANSVERSE STRENGTH OF IRON "B"

CHEMICAL ANALYSIS:

TC	2.90	S	0.04
Si	1.55	P	0.03
Mn	1.00	Ni	2.23

BRINELL HARDNESS:

As cast	255
Oil quenched at 825 degs. Cent. (1517 degs. Fahr.).....	450
Oil quenched at 825 degs. Cent. (1517 degs. Fahr.)	
and drawn at 425 degs. Cent. (797 degs. Fahr.).....	340

SHEAR STRENGTH:

	Kg. per sq. mm.	Lbs. per sq. in.
As cast	36.7	52,180
Oil quenched at 825 degs. Cent. (1517 degs. Fahr.)		
and drawn at 425 degs. Cent. (797 degs. Fahr.)	55.7	79,190

TRANSVERSE STRENGTH (same sample as in Table 4):

	Kg. per sq. mm.	Lbs. per sq. in.
As cast	830	1830
Oil quenched at 825 degs. Cent. (1517 degs. Fahr.)		
and drawn at 425 degs. Cent. (797 degs. Fahr.)	920	2029

while the Brinell hardness is negligibly affected by drawing at 300 degs. Cent. (572 degs. Fahr.), as shown by the data of Tables 4 and 5.

33. It will be noted that suitable heat treatment provided for improved mechanical properties as well as considerably increased hardness, the improvement more or less depending on drawing temperature. No cracking of the iron may be feared so long as the heat treatment is conducted correctly. Low quenching temperatures are beneficial from this point of view since they limit the danger of cracking in the neighborhood of the graphite flakes.

34. The method of hardening machinable cast irons as described in this paper is very flexible and has been applied in France in several industrial applications, as for automobile cylinder liners, blocks and piston rings, gears and cams, motorcycle and airplane engine cylinders, etc.* Taking the case of a ribbed air-cooled motorcycle or airplane engine cylinder casting as an example of one of the more delicate operations, where experience has shown that quenching in oil or an air blast, or even in calm air, cannot

* Various applications have been cited by R. Chavy in his communication "Recent Studies and Applications of Quenched and Over-Quenched Cast Irons" before the Internatl. Foundry Congress at Milan, Italy, September, 1931.

be undertaken without fear of cracking, any one of the following solutions can be resorted to, according to the hardness desired:

(a) An iron containing 3.5 to 4 per cent nickel, hard as cast and softened by drawing to obtain a hardness of 300 to 320 Brinell, this permitting machining by the usual methods.

(b) An iron hard as cast (as above), softened at about 675 degs. Cent. (1247 degs. Fahr.) for machining, reheated after machining, to 825-850 degs. Cent. (1517-1562 degs. Fahr.) and cooled slowly either in the furnace or pit to obtain a Brinell hardness of 350 to 375, followed by drawing at about 300 degs. Cent. (572 degs. Fahr.)—which slightly decreases the hardness—and finally, finishing the completed castings by grinding or similar methods.

(c) Finally, although not applying strictly under the term "heat treatment," it is possible to obtain, by suitable adjustment of composition, castings which "as cast" have Brinell hardness of over 280 and which are machinable. Nevertheless, as has been previously remarked, small variations in composition will result in either too high or too low a hardness. If a Brinell of 300 to 320 is desired, it is preferable to employ the first of the solutions mentioned.

The Use of Silicon and Manganese Briquets in the Cupola

BY LYNN H. RANSOM,* BEAVER FALLS, PA.

Abstract

This paper presents the results of a number of gray cast iron heats made by the addition of silicon and manganese briquets to the cupola charge. Comparisons are made with heats of similar analysis produced with larger percentages of pig iron in the charge. Tables of results, and photomicrographs, indicate that it is possible to produce high-grade castings economically with briquetted alloys.

1. Considerable thought has been given to economies that might be affected in the foundry by the increasing demand for lower costs, with the result that labor and raw materials have been scrutinized repeatedly as possible items for revision. Our attention was drawn to the briquetted alloys and the control of chemical composition claimed for these products; accordingly, we decided to investigate this practice in a series of experiments, as we have always felt that satisfactory operation of the foundry was governed closely by the ability to regulate the chemical analysis of the metal.

2. The major portion of our castings must machine freely yet possess adequate strength to meet the demands of the engineering department. We find that the conditions stated by Howe in regard to carbon in cast iron are a source of considerable benefit to us.

3. He detected an increase in strength with increased percentages of combined carbon up to one per cent, but an adverse effect on machinability as the combined carbon increased with a decrease in the graphitic carbon; and further, that this ratio of combined carbon to graphitic carbon intensified these results as the total carbon was decreased. We find that silicon is the most effective medium to control this ratio, and consequently experimented with various amounts of the silicon briquets.

* Keystone Driller Co.

4. Whereas the operator of an electric furnace or air furnace has facilities to promote the solution of graphite, the average cupola operator is restricted in this regard and he must resort to other methods for similar results. By choosing scrap which has been previously melted in the cupola and steel rails for the charge, there is less likelihood of finding large flakes of graphite in the castings.

5. However, the iron may be too hard to machine freely on account of the lack of sufficient silicon which can be satisfactorily increased by including silicon briquets with the charge. Also, as the silicon is not released until the melting zone is reached, it was expected that conditions comparable to the practice developed by Corsalli, of treating liquid iron with molten ferrosilicon and manganese shortly before casting, could be met.

6. The briquets are made of crushed ferroalloys and a cement binder of sufficient strength to resist rough handling. Each briquet contains a definite weight of the metallic element so that additions are made by number rather than by weight.

Experimental Work

7. Prior to the use of briquets we regularly employed a mixture consisting of 45 to 50 per cent pig iron, 10 per cent steel scrap and the balance purchased iron scrap with returned spews and risers. The usual run of small and large castings are such as found in most jobbing foundries and are for use in road-building equipment, drilling machines, boilers and pumps. They vary in weight from 3 lbs. to 500 lbs., the heaviest section of which is 3 inches.

8. Seventeen hundred pounds of iron are drawn from the cupola at each tap. The average strength of the iron was approximately 34,000 lbs. per sq. in. tensile strength, 2300 lbs. transverse strength, deflection 0.23 in., with a Brinell hardness around 190. The physical properties were obtained from standard A. S. T. M. arbitration bars 1.20 in. in diameter and tested on 18-in. centers.

9. Each table accompanying this paper represents the average of four tests taken from separate ladles throughout the heat. The tensile tests are turned from the fractured transverse bar. Our average iron analyzed 3.30 per cent total carbon, 0.50 per cent

Table 1

CUPOLA AND MATERIALS USED

Cupola:

Shell, 72 in. lined to 48 in.
 Tuyeres, Six 5 in. \times 19 in.
 Height of coke bed, 40 in. above tuyeres.
 Blast pressure, 12 to 14 oz.
 Average time between charging and blast on, $1\frac{1}{2}$ hrs.
 Time between blast on and first iron, 10 min.
 Air supply, positive-type blower.

Materials of Charge:

Pig Iron—	No. 1 Soft.	No. 2 Fdy.	No. 2X Soft.
Manganese	0.68	0.57	1.28
Phosphorus	0.35	0.54	0.38
Sulphur	0.023	0.048	0.033
Silicon	3.24	2.20	2.79

Foreign Scrap—	Machinery Cast Scrap.
Manganese	0.60
Phosphorus	0.60
Sulphur	0.09
Silicon	1.85

Steel Scrap—	Sheet Bar		—Cast Spreads—		
	Rail Ends.	Crops.			
Manganese	0.67	0.60	1.98	2.20	1.40
Phosphorus	0.03	0.025	0.05	0.05	0.05
Sulphur	0.035	0.030	0.05	0.05	0.05
Silicon	0.20	0.15	0.24	0.31	0.33

Coke—

Moisture	0.81
Fixed carbon	89.10
Volatile matter	0.86
Ash	10.13
Sulphur	0.70

*Limestone—.....**Briquets—*

Silicon—weigh 5 lbs., contain 2 lbs. silicon.
 Manganese—weigh $3\frac{1}{2}$ lbs., contain 2 lbs. manganese,
 $\frac{1}{2}$ lb. silicon.

combined carbon, 2.80 per cent graphitic carbon, 0.70 per cent manganese, 0.48 per cent phosphorus, 0.085 per cent sulphur, and 2.10 per cent silicon.

Cupola Operation

10. After the sand bottom is made up, sufficient wood for igniting the coke is placed in the cupola and covered with approximately two-thirds of the total coke for the bed charge. After this has uniformly burned through, the balance of the coke—suffi-

Table 2

Charge: 400 lbs. No. 2 pig iron.			
500 lbs. No. 2X pig iron.			
900 lbs. Cast iron scrap.			
125 lbs. Cast steel scrap.			
75 lbs. Sheet bar crops.			
Results:	TC 3.30	Manganese	0.75
	GC 2.77	Phosphorus	0.45
	CC 0.53	Sulphur	0.088
		Silicon	2.18
Transverse strength			2415 lbs.
Deflection			0.235 in.
Tensile strength			34,625 lbs. per sq. in.
Brinell hardness			199

Table 3

Charge: 400 lbs. No. 2 pig iron.			
600 lbs. No. 2X pig iron.			
800 lbs. Cast iron scrap.			
100 lbs. Cast steel scrap.			
100 lbs. Sheet bar crops.			
Results:	TC 3.32	Manganese	0.75
	GC 2.87	Phosphorus	0.470
	CC 0.45	Sulphur	0.085
		Silicon	2.07
Transverse strength			2233 lbs.
Deflection			0.224 in.
Tensile strength			34,775 lbs. per sq. in.
Brinell hardness			193

cient to raise the bed to 40 inches above the tuyeres—is added and charging started. About 30 lbs. of limestone is used on top of each coke charge.

11. The order of charging is, first, steel scrap, followed by pig iron, then heavy scrap, and finally the light sprows and risers. The average number of charges is eight, of 2000 lbs. each. Approximately 275 lbs. of coke is used between charges. This mixture gives the desired chemical analysis and good physical properties for this type of cast iron. Details of cupola and charge are shown in Table 1. The data of Tables 2 and 3 represent results of two average heats.

Silicon Recovery Ascertained

12. In order to ascertain the recovery of silicon from the briquets and the effect on the physical properties of the iron, without jeopardizing the castings and at the same time learning

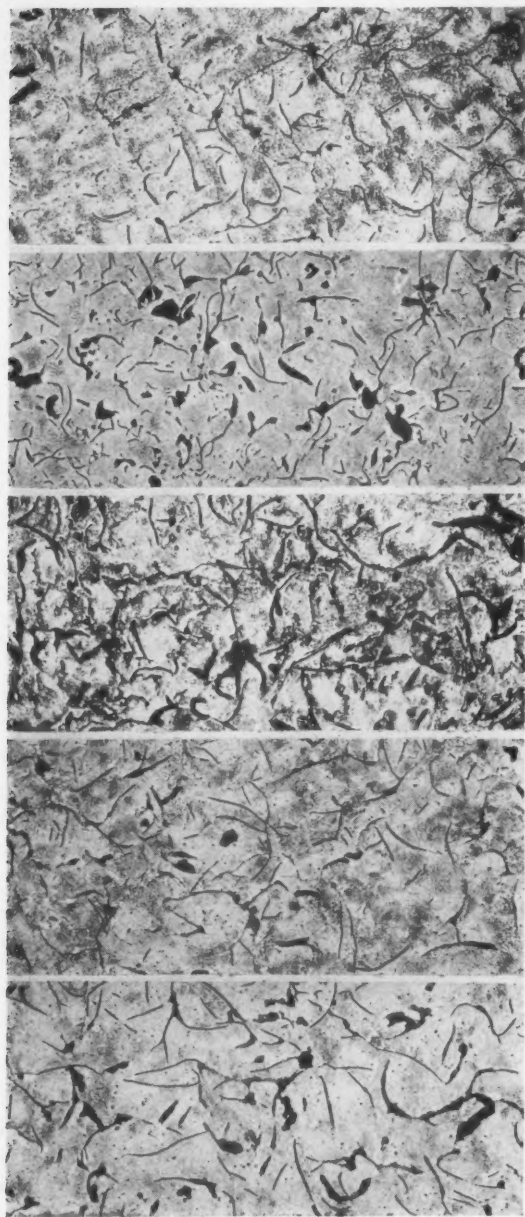


FIG. 1.—PHOTOMICROGRAPHS OF PIG IRON AND BRIQUET MIXTURES. X100. A: PIG IRON MIXTURE CONTAINING 10 PER CENT STEEL. (SEE TABLES 2 AND 3.) B: BRIQUET MIXTURE CONTAINING 10 PER CENT STEEL. (SEE TABLE 4.) C: PIG IRON MIXTURE CONTAINING 20 PER CENT STEEL. (SEE TABLE 5.) D, E: BRIQUET MIXTURES CONTAINING 20 PER CENT STEEL. (SEE TABLES 6 AND 9, RESPECTIVELY.)

Table 4

Charge: 800 lbs. No. 2 pig iron.			
1000 lbs. Cast iron scrap.			
200 lbs. Cast steel scrap.			
3, 2-lb. Silicon briquets.			
Results: TC	3.31	Manganese	0.75
GC	2.77	Phosphorus	0.466
CC	0.54	Sulphur	0.092
		Silicon	2.18
Transverse strength 2209 lbs.			
Deflection 0.218 in.			
Tensile strength 35,000 lbs. per sq. in.			
Brinell hardness 194			

Table 5*Pig Iron Mixture*

Charge: 900 lbs. No. 1 pig iron.			
700 lbs. Cast iron scrap.			
400 lbs. Cast steel scrap.			
Results: TC	3.20	Manganese	0.69
GC	2.68	Phosphorus	0.436
CC	0.52	Sulphur	0.105
		Silicon	2.29
Transverse strength 2645 lbs.			
Deflection 0.269 in.			
Tensile strength 35,900 lbs. per sq. in.			
Brinell hardness 189			

Table 6*Briquet Mixture*

Charge: 600 lbs. No. 2 pig iron.			
1000 lbs. Cast iron scrap.			
200 lbs. Cast steel scrap.			
200 lbs. Sheet bar crops.			
3 lbs. Std. ferromanganese.			
5, 2-lb. Silicon briquets.			
Results: TC	3.02	Manganese	0.75
GC	2.54	Phosphorus	0.408
CC	0.48	Sulphur	0.089
		Silicon	2.03
Transverse strength 2451 lbs.			
Deflection 0.221 in.			
Tensile strength 37,550 lbs. per sq. in.			
Brinell hardness 206			

Table 7

Pig Iron Mixture

Charge: 300 lbs. No. 2X pig iron.
 600 lbs. No. 1 pig iron.
 500 lbs. Cast iron scrap.
 400 lbs. Rail ends.
 200 lbs. Cast steel scrap.
 14½ lbs. 50% ferrosilicon.

Results: TC	3.06	Manganese	0.66
GC	2.66	Phosphorus	0.342
CC	0.40	Sulphur	0.084
		Silicon	2.40

Transverse strength	2260 lbs.
Deflection	0.218 in.
Tensile strength	35,650 lbs. per sq. in.
Brinell hardness	205

Table 8

Briquet Mixture

Charge: 600 lbs. No. 2 pig iron.
 800 lbs. Cast iron scrap.
 350 lbs. Cast steel scrap.
 250 lbs. Sheet bar crops.
 8, 2-lb. Silicon briquets.

Results: TC	2.99	Manganese	0.67
GC	2.46	Phosphorus	0.372
CC	0.53	Sulphur	0.113
		Silicon	2.13

Transverse strength	2375 lbs.
Deflection	0.210 in.
Tensile strength	38,900 lbs. per sq. in.
Brinell hardness	212

the effects under normal operating conditions, we altered the charge to include three silicon briquets and obtained encouraging results, as shown in Table 4. The only change in charge practice other than given above was to place the briquets directly on the coke, covering them with the balance of the charge.

Increase of Steel

13. The cost of this mixture was slightly under that of our standard charges, and it was decided to increase the proportion of steel to obtain increased physical properties. Twenty per cent steel was used, and in the first instance 45 per cent pig iron was charged to obtain the desired analysis. The briquet mixture contained 30 per cent pig iron and the analysis was adjusted by the

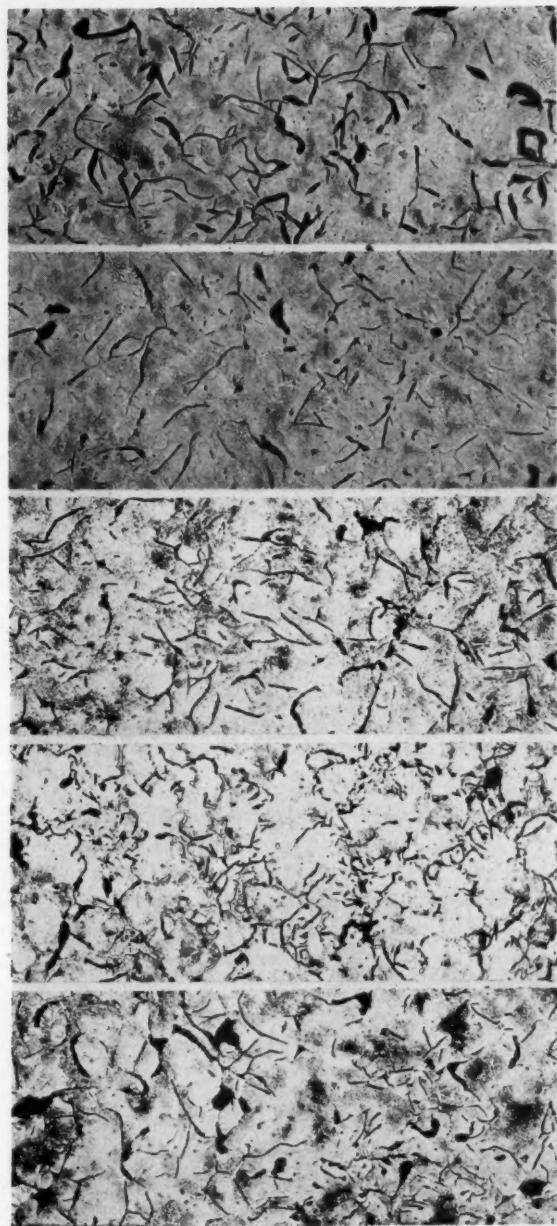


FIG. 2—PHOTOMICROGRAPHS OF PIG IRON, BRIQUET, AND ALL SCRAP AND BRIQUET MIXTURES X100. A: FIG IRON MIXTURE CONTAINING 30 PER CENT STEEL. (SEE TABLE 7.) B: BRIQUET MIXTURE CONTAINING 30 PER CENT STEEL. (SEE TABLE 8.) C, D, E: ALL SCRAP AND BRIQUET MIXTURES, ALL CONTAINING 20 PER CENT STEEL. (SEE TABLES 10, 11, AND 12, RESPECTIVELY.)

addition of silicon briquets and standard ferromanganese. The results obtained are given in Tables 5 and 6, and we were somewhat surprised at the reduction in total carbon content of the iron made with briquets.

14. In view of the improved results, 30 per cent steel charges were made under similar conditions, and again a reduction in total carbon content was obtained (see Tables 7 and 8). The deficiency of silicon was adjusted by the addition of lump ferrosilicon to the charge.

Manganese Additions by Briquets

15. We had been using medium manganese steel scrap in order to adjust the manganese content of the iron, and about

Table 9

Charge:	600 lbs. No. 2 pig iron.		
	1000 lbs. Cast iron scrap.		
	400 lbs. Rail ends.		
	2 Manganese briquets.		
	3, 2-lb. Silicon briquets.		
Results: TC	3.11	Manganese	0.69
GC	2.63	Phosphorus	0.371
CC	0.48	Sulphur	0.098
		Silicon	2.15
Transverse strength	2285 lbs.		
Deflection	0.223 in.		
Tensile strength	38,800 lbs. per sq. in.		
Brinell hardness	212		

this time manganese briquets were placed on the market. It was decided to try these in conjunction with silicon briquets in order to check their efficiency. Owing to the fact that a number of fairly light sectioned castings are produced, the 30 per cent steel mixture gave slightly too great hardness and we decided to continue our experiments using 20 per cent steel charges. The results of the use of manganese briquets are given in Table 9.

Heats Without Pig Iron

16. Having proven to our satisfaction that the briquets were beneficial from a standpoint of cost and uniformity of results, and that from photomicrographs they evidently had a cleansing and scavenging effect on the iron, we decided to make a heat using no

Table 10

Charge: 1000 lbs. Remelt.			
600 lbs. Foreign scrap.			
400 lbs. Rail ends.			
2 Manganese briquets.			
5, 2-lb. Silicon briquets.			
Results: TC	2.94	Manganese	0.59
GC	2.47	Phosphorus	0.347
CC	0.47	Sulphur	0.105
		Silicon	2.03
Transverse strength		2460 lbs.	
Deflection		0.239 in.	
Tensile strength		41,075 lbs. per sq. in.	
Brinell hardness		212	

Table 11

Charge: 1000 lbs. Foreign scrap.			
600 lbs. Remelt.			
400 lbs. Cast steel scrap.			
14, 1-lb. Silicon briquets.			
Results: TC	2.88	Manganese	0.66
GC	2.20	Phosphorus	0.353
CC	0.68	Sulphur	0.120
		Silicon	2.22
Transverse strength		2270 lbs.	
Deflection		0.205 in.	
Tensile strength		41,860 lbs. per sq. in.	
Brinell hardness		212	

Table 12

Charge: 1000 lbs. Foreign scrap.			
600 lbs. Remelt.			
400 lbs. Rail ends.			
3 Manganese briquets.			
14, 1-lb. Silicon briquets.			
Results: TC	2.89	Manganese	0.63
GC	2.20	Phosphorus	0.356
CC	0.69	Sulphur	0.118
		Silicon	2.26
Transverse strength		2380 lbs.	
Deflection		0.201 in.	
Tensile strength		41,500 lbs. per sq. in.	
Brinell hardness		207	

pig iron. In this experiment both manganese and silicon briquets were used to adjust the percentage of these elements to that desired, as shown in Tables 10 and 11.

17. Table 12 represents an all-scrap heat using both silicon and manganese briquets to adjust the analysis.

CONCLUSIONS

18. We feel that the results obtained justify our contentions that the use of remelted iron and ferroalloys in the briquetted form is beneficial. This is confirmed by the improvement in physical properties. Simultaneously, a considerable reduction in cost was obtained, especially in the all-scrap mixtures, where the net saving was more than \$2.00 per ton.

19. Our experiments lead us to believe that the apparent delay in melting of the alloy contained in the briquet is an important feature which cannot be obtained by adding the unprotected alloy to the charge. The binder seems to protect the addition to such an extent that alloying is similar to that of Corsalli's practice, and the uniform analysis of individual ladles indicates that concentrated additions are not harmful. In this connection it was noted that the variation in analyses from ladle to ladle was no greater than when using pig iron.

20. An examination of the photomicrographs discloses that there is considerable decrease in the size of the graphitic carbon flakes in the briquet iron mixture as compared with those obtained in iron made with considerable pig iron in the charge. Whether this is entirely due to the use of remelted iron or partly to the use of briquets, is problematical, but it is believed that the scavenging and deoxidizing action of the alloys on the molten iron plays an important part in the general improvement in physical properties. (See photomicrographs, Figs. 1 and 2.)

21. An interesting point is the low total carbon found in the all-scrap heat in which only 20 per cent steel was used. The amount of carbon in the steel scrap apparently did not affect the results.

22. In our experiments we learned that the type of scrap used had an influence on the recovery of silicon and manganese from the briquets. Using clean scrap, the recovery was higher than when badly oxidized or extremely light scrap was used. This

variation also was found in the pig iron mixtures, but no difficulty was encountered from this source.

23. We have been advised by the producers that they believe the recovery also depends on the characteristics of the individual cupola. In our case, the recovery of the alloy from the briquets was 85 per cent of the added silicon and 77 per cent of the manganese.

DISCUSSION

ORAL DISCUSSION

E. K. SMITH:¹ I have been working with these briquets for some months, and I wish to emphasize one point in regard to recovery of alloys in the final casting. The recovery depends largely on cupola practice and the class of material. Mr. Ransom is correct in saying that the briquets act as deoxidizers; in rusty scrap there will be more loss of silicon and manganese.

An interesting point we have found is in connection with the use of all-scrap charges. Many foundrymen have been using all scrap, taking advantage of present subnormal prices and using briquets with the scrap. With much remelt material, the sulphur usually increases, in which case one must desulphurize in a forehearth. In this way we produced good iron.

We have performed quite a bit of work using the chrome in briquet form and adding it to the cupola charge, usually with nickel additions in the ladle to achieve the chrome-nickel combination. For some time we have obtained finer graphite with a low-silicon pig; for example, pig iron containing 1.25 per cent silicon with briquet additions in the cupola would give a finer graphite of higher strength than 4.00 per cent silicon pig with a similar mixture.

MEMBER: We have conducted rather extensive tests in a cupola of very small capacity, making castings which require very dense structure. Our work was based on the theory that by adding the briquets in bonded form and having them reach the heart of the cupola before being melted, they would act as a deoxidizing agent. Our results have substantiated that theory; we tried various mixtures and checked the results.

With certain mixtures our recovery was very high; with high scrap and a dirty scrap mixture, recovery was low. We obtained recoveries

¹ Metallurgist, Electro Metallurgical Sales Corp., Chicago.

of silicon of around 80 per cent. On manganese the recovery was almost 85 per cent in some cases, and down to 60 per cent in other cases although they made good castings. Results have been so gratifying that our plant now is following this practice all the time.

CHAIRMAN H. BORNSTEIN:³ Mr. Ransom pointed out the increase in strength obtained by decreasing the percentage of pig iron, which I believe was to be expected. We had a similar case at one of our plants when trying to take advantage of the low scrap market.

We kept the composition uniform and decreased the amount of pig iron, and in doing this we decreased our total carbon and obtained iron too strong for our particular use. Our trouble lay not in getting iron strong enough but in getting iron that was too strong; it resulted in difficulties in hardness and machinability.

As a general rule, I believe that in going from a pig iron mix to an all-scrap mix it probably will be found that the iron increases in strength rather than decreases, due to lowering of the total carbon content. In our own case we solved the problem by decreasing the amount of steel used. We dropped from 10 to 15 per cent down to about 5 per cent and even less, in order to obtain the physical properties formerly obtained with the higher pig iron mix.

MEMBER: Did the author make a comparison of the iron when he used ferrosilicon and ferromanganese, and then the briquet of silicon and manganese, versus pig iron?

L. H. RANSOM: In the pig iron mixture we used 14½ lbs. of 50 per cent ferrosilicon, and in the briquet mixture we used eight 2-lb. silicon briquets. These results are given in Tables 7 and 8 of the paper.

MEMBER: Then there is no comparison of the scrap mixture versus the scrap mixture with ferrosilicon? I was trying to figure how much was due to the fact that it was a scrap mixture and how much was due to the use of briquets.

³ Director, Testing and Research Laboratories, Deere & Co., Moline, Ill.

The Production and Application of Manganese Steel in Australia*

By D. CLARK AND J. COUTTS, NEWCASTLE, N. S. W., AUSTRALIA

Abstract

In Australia, manganese steel castings are used for a variety of purposes, especially for wear resistance. With rolled rails or cast points and crossings, the life of manganese steel as compared with carbon steel of the grade generally used for these purposes has been proved to be not less than 4 to 1, and may run as high as 9 to 1. The various processes for making manganese steel are described and the advantages and disadvantages of each are discussed. The properties obtained by varying analysis are compared. Heat treatments are listed and work hardening effects discussed. Attention to design factors and correct risering is stressed.

1. To Sir Robert Hadfield belongs the honor of having instituted the initial research in the field of alloy steels, and his discovery of manganese steel represents an event of outstanding importance in the progress of engineering. Without in any way overstressing his claim, he might also be regarded as having pioneered the effort to lift the art of heat treatment of steel out of the region of empirics by focusing the searchlight of scientific reasoning on its problems.

2. It is strange indeed that the product of this early research should have resulted in evolving a steel so unique in its way, and little imagination is required to visualize the immense amount of work that was necessary before its marketing as castings or in the form of rolled and forged products became an accomplished

* Exchange paper presented on behalf of the Bureau of Steel Manufacturers of Australia.

fact. This achievement could only have been made possible by the exercise of painstaking effort and a high courage.

3. Other investigators, earlier or contemporary, undoubtedly had inquired into the effect of various alloying elements in steel, but their interest would appear to have ebbed in finding themselves up against apparent anomalies and difficulties. The inventor's experiments commenced in the year 1882, and two years later came the culmination of his work when patents were granted for what is now known as "Hadfield's manganese steel." That it has been of immense service to the engineering world is undoubted, and its true value may be gaged from the fact that, despite the ever-expanding ranges of alloy steels, no steel has supplanted the

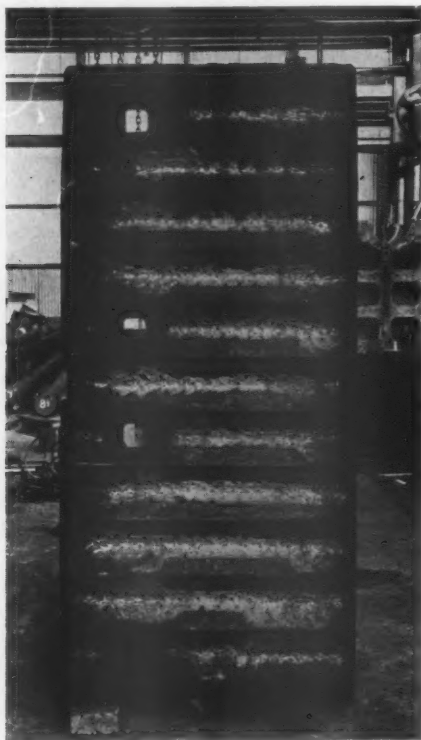


FIG. 1—TYPICAL CASTING OF MANGANESE STEEL. JAW OF AN 84-INCH BY 60-INCH CRUSHER.

original manganese steel in those particular applications for which it has been found peculiarly suited.

4. Among all the alloy steels known, there is perhaps none the quality of which is less affected for most purposes by the process selected for its manufacture. If one wished to produce the highest quality of most other alloy or high-grade carbon steels, there are only two processes that would be considered, namely, the crucible and the electric furnace, provided these processes were capable of supplying the quantity required for a single purpose, while the last choice would probably be the Bessemer.

5. During the early years succeeding its discovery, manganese steel was produced mainly by the Bessemer and Tropenas processes,



FIG. 2—TYPICAL CASTING OF MANGANESE STEEL. RAILWAY AND ELECTRIC TRAMWAY CROSSING MANUFACTURED BY C. RUWOLT, PROPRIETARY, LTD., MELBOURNE, AUSTRALIA.

and although the tendency today is to utilize the electric and open-hearth plants in increasing measure, it is very doubtful whether the average product obtained gives much if any better service than that made in converters when the steel was first introduced. Foundry technique, however, has and still is being improved, and it may be fairly claimed (insofar as the part the foundryman plays) that the present-day casting is a more workmanlike job.

6. In Australia, manganese steel castings are used for a variety of purposes such as stamp mills, railway points and crossings, liners for tube mills, brick and tile machinery, gears and chain sprockets, crusher, dredger and excavator parts, shields for lifting magnets, etc. Typical manganese steel castings are shown in Figs. 1 and 2.

7. As is well known, the successful application of austenitic manganese steel depends chiefly on the conditions under which it operates, and it is generally accepted that satisfactory service may be expected only where percussive action predominates. This premise, however, is not strictly accurate, since an equal efficiency may be obtained by rolling action, the degree depending upon the load carried.

8. In the case of rolled rails or cast points and crossings, the life of manganese steel compared with carbon steel of the grade generally used for these purposes has been proved to be not less than 4 to 1, and may be anything up to 9 to 1.

9. In castings with design showing abrupt changes of section, and which may be subjected to shocks of any magnitude, care is necessary to see that they are adequately supported in position practically over their entire area, because the characteristically low limit of elasticity which manganese steel exhibits may cause it to bend readily where there is semblance of an overhang, or fracture prematurely at a sharp-angled intersection. Wherever possible, therefore, all sharp corners should be rigidly guarded against.

STEEL MAKING

10. Manganese steel containing, say, 12.5 to 13.5 per cent of manganese has a melting point of about 1345 degs. Cent. (2453 degs. Fahr.), while that of 1 per cent carbon steel is 1435 degs. Cent. (2615 degs. Fahr.). It thus has a lower melting point than plain steel of equivalent carbon.

11. It has a high degree of fluidity, and in good practice advantage is taken of this to keep the temperature low, not only because of the erosive effect that increasing temperature has on the furnace lining, ladles and molds, but also because the higher the temperature, the greater is the loss of manganese alloy. Similarly, the duration of the pouring period also has an effect on manganese efficiency.

12. Illustrating this, the data of Table 1 are submitted showing the erosive effect of manganese steel on the ladle lining and molds, evidenced by the progressive increase in silicon and the part that time plays in the loss of manganese during pouring. It might be stated that the casting temperature of this particular heat was higher than normal.

Table 1

EROSIVE EFFECT OF MANGANESE STEEL ON LADLE LINING AND MOLDS

	C	Si	Mn	P	S
	%	%	%	%	%
2:05 p.m. Furnace sample.....	1.48	0.12	14.15	0.047	0.011
2:15 p.m. Furnace tapped					
2:19 p.m. Sample taken.....	1.46	0.22	13.47	0.049	0.005
2:33 p.m. Sample taken.....	1.42	0.59	12.21	0.049	0.001
2:43 p.m. Sample taken.....	1.45	0.79	11.74	0.049	0.002

13. Two points emerge from these data: (1) The desirability of keeping the temperature reasonably low so as to minimize the attack on the siliceous linings and molds, and (2) the necessity for getting rid of the steel quickly so as to insure some degree of uniformity in the manganese content from the beginning to the end of the pour. It is characteristic of manganese steel that, although the manganese in the samples quoted in Table 1 vary, there was no observable difference in their physical properties after suitable heat treatment.

14. A steel of excellent quality can be obtained from the basic electric furnace by using an all-manganese scrap charge, which has the virtue that only a small amount of ferromanganese is necessary to bring the bath to the required analysis. Apart from the economic aspect, this feature is of importance when it is considered that the ferromanganese additions are made necessarily at a late stage of the process, and that the larger the addition, the greater is the drop in the bath temperature—which takes time and care to readjust.

15. In the converter process, the ferromanganese is added in the fluid condition to the blown iron in the ladle, or vice versa. Consequently, the oxidation losses are much higher than in the electric furnace when the atmosphere is for the most part reducing, except in the vicinity of the charging doors. Even in those areas, however, something approaching reducing conditions can be obtained if the doors are kept reasonably tight to prevent the infiltration of excess air.

16. In those Australian plants where steel is made by the electric process, the type of furnace in general use is the Heroult. Where the converter is the steel-making unit employed, the side-blown Tropenas type is used in conjunction with a crucible furnace for melting the ferromanganese.

17. In running a typical heat, the converter charge is blown down in a manner similar to that followed for the production of soft carbon steel, and a silicon addition to give 0.15 per cent of that element in the finished manganese steel is made to the ladle. After standing five minutes, a measured volume of blown metal is added to the molten ferromanganese, which has previously been transferred from the crucibles to a graduated mixing ladle. The metal is then skimmed and lightly dusted with silica sand.

18. Small castings are poured from hand shanks, while those of heavier section are lip-poured from the crane ladle as the metal progressively cools. Steel of very consistent chemical content is produced by this method of manufacture. Sixteen heats made recently for one type of casting showed the following:

	Maximum.	Minimum.	Average.
Manganese, per cent.....	13.0	11.8	12.3
Carbon, per cent.....	1.32	1.28	1.3

19. Variations in chemical composition are sometimes specified for particular purposes, and one company making steel by the converter process has been called upon to produce manganese steel with a carbon content as low as 0.75 per cent. How these castings compared with those of the traditional analysis is not yet known.

20. When the method of casting is by way of a bottom-pour ladle, the erosive effect is such that the cutting action on the nozzle may be very severe when the fireclay type is used. This not only tends toward reduced metal recovery at times due to leaking stoppers, but it may also affect the quality of the castings. Therefore, when using fireclay nozzles it is necessary to select one with the best surface obtainable and to see that the stopper is fitted to insure a perfect seal.

21. While the latter precautions are helpful, the substitution of magnesite nozzles in place of fireclay results in greater efficiency, as it is found that the cutting action of manganese steel on this nozzle is negligible as compared with that on the fireclay type.

ANALYSIS

22. Until the introduction of the super-high-speed steels, the drilling of manganese steel samples for analysis alone was a problem. A common practice is to heat treat the test block at

a low temperature, say, around 450 degs. Cent. (842 degs. Fahr.), and drill when cold. Greater ease of drilling is obtained when an ordinary high-speed drill is used, by heating the sample uniformly then drilling hot so that blue-tinted cuttings are obtained.

23. An expressed doubt that such drillings are not capable of giving a true analysis was refuted on investigation. No variation whatever was observable on comparative analysis made between the slightly oxidized and the usual bright drillings.

24. Hadfield's original specification provided for carbon 0.95 to 1.50 per cent and manganese 10.0 to 15 per cent. Generally, the carbon-manganese ratio of approximately 1 to 10 is still preserved.

25. Lately, however, there is a tendency to lower the carbon to around 0.90 per cent, keeping the manganese at 12.00 per cent minimum. This involves the provision of a lower-carbon ferromanganese alloy than is habitually used. It is claimed that superior service is obtained from castings of the lower carbon content, although the authors have no reliable data to confirm or deny this assertion.

26. Assuming, however, that there is no virtue in the lower carbon analysis so far as wear is concerned (and we are frankly skeptical), greater freedom from contraction cracks or pulls may result. In other words, it may be found that the lower carbon content shows the steel to have reduced the tendency to brittleness while cooling in the mold after casting, more than when the 1 to 10 ratio or thereabouts is observed. Viewed from that angle, this analysis may possess economic manufacturing advantages.

27. With regard to the effect of phosphorus on the properties of manganese steel, it is noticed that some users' specifications limit this element to a maximum of 0.06 per cent. While the question of keeping the phosphorus to reasonable limits on alloy steels may be accepted in a general sense, the same necessity does not arise in respect to manganese steel. Some of the best manganese steel of which there are records contains up to 0.12 per cent phosphorus.

28. Again, it is suggested that it is desirable to have the manganese around 14 per cent rather than 10 per cent. Considering that the ferromanganese itself contains approximately 0.25 per cent of phosphorus, obviously it is impossible to consistently fulfill both conditions on an ordinary manufacturing basis.

29. The tentative specification recently adopted by the American Society for Testing Materials for austenitic manganese castings would appear to have been based on experience and with due regard for the interests of manufacturer and user alike. This specification is considered sound, and provides for

Carbon, per cent.....	1.00 to 1.40
Manganese, per cent.....	10.00 to 14.00
Phosphorus, per cent.....	not over 0.10

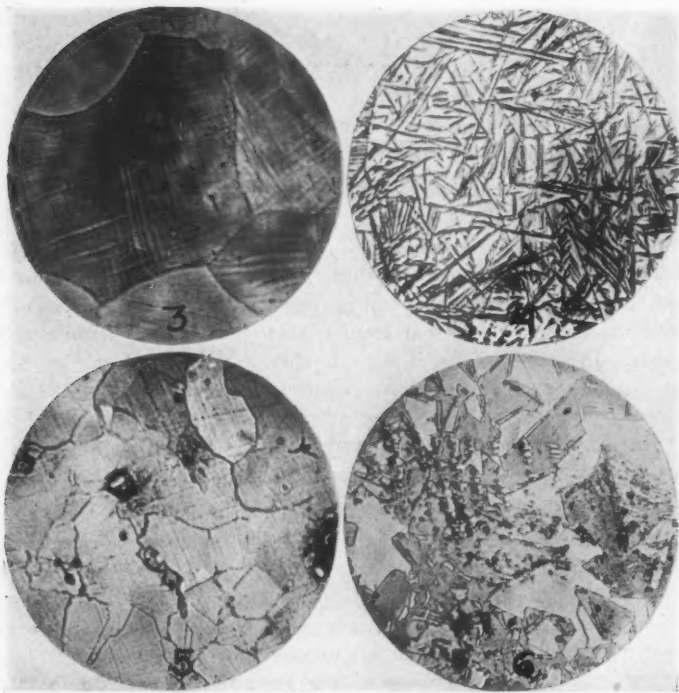


FIG. 3—IDEAL AUSTENITIC CONDITION IN MANGANESE STEEL.

FIG. 4—PURELY MARTENSITIC STRUCTURE ARISING FROM AN ABNORMALLY HIGH CARBON HEAT QUENCHED AT AN UNSUITABLE TEMPERATURE.

FIG. 5—SAME MATERIAL AS SHOWN IN FIG. 4, BUT REQUENCHED FROM 1060 DEGS. CENT. (1940 DEGS. FAHR.), WHEN SMALL GRAINED AUSTENITIC STRUCTURE WAS OBTAINED.

FIG. 6—PHOTOMICROGRAPH OF MANGANESE STEEL, OF SECTION CUT FROM WORK-HARDENED AREA. 100X.

HEAT TREATMENT

30. Bearing in mind its brittle nature as cast and until actually quenched, it is obvious that not only should the heat treatment be carefully controlled but that the castings must be carefully handled during charging and withdrawal from the furnace.

31. Due to its well-known low order of heat conductivity, and also to avoid overheating the lighter sections, it is necessary to heat slowly (100 degs. Cent.—212 degs. Fahr.—per hour is a suitable rate of heating), until a medium cherry-red color is attained, say, at 750 degs. Cent. (1382 degs. Fahr.) Soak at this temperature to insure uniformity throughout the charge, then accelerate the heat input until the desired temperature is reached. On account of the facility with which surface decarburization takes place, it is not desirable to prolong the final soaking period beyond that required for equalization of the temperature throughout, because a decarburized surface induces skin brittleness.

32. Some recent work by Svecnicov indicates that the maximum tenacity and minimum loss by abrasion is obtained by heating to 1150 degs. Cent. (2102 degs. Fahr.) This temperature seems excessive and, while good properties may be secured on certain casts experimentally treated where it is possible to grind off the resultant embrittled skin, it is neither desirable nor practicable to do this on a production basis.

33. The correct final toughening temperature to bring the best results depends to a large extent on the temperature at casting, and on the speed of pouring. When the casting temperature is low and the speed of pouring high, the temperature limits producing the ideal condition lie between 1000 and 1040 degs. Cent. (1832 and 1904 degs. Fahr.) It is only when the casting temperature is excessive or the carbon is too high in relation to the manganese that it is necessary to exceed the top limit given.

34. Fig. 3 shows the ideal austenitic condition, while Fig. 4 exhibits a purely martensitic structure arising from an abnormally high carbon heat quenched at an unsuitable temperature. The analysis of this steel showed 1.68 per cent carbon and 14.60 per cent manganese.

35. A further sample was requenched from 1060 degs. Cent. (1940 degs. Fahr.) and examined under the same magnification.

The carbides were found to have been dissolved and a small grained austenitic structure was obtained, as shown in Fig. 5.

36. In quenching, it is highly desirable to extract the heat as rapidly as possible, and to insure this a copious supply of cold water should be constantly flowing into the tank, and the hot water drawn off. It is well known that in reheating a toughened sample the steel becomes brittle at around 400 degs. Cent. (754 degs. Fahr.) Therefore, to make certain that the austenitic condition is retained completely, it is necessary to quench to a temperature definitely below this.

37. Considering the question of mass, there is a limit in thickness beyond which manganese steel should not be used as castings, particularly if subjected to heavy impact or bending moment in service. Five inches is suggested as the absolute maximum section that should be used, and only then under particularly favorable circumstances. For general purposes, the thickness should not exceed three inches.

38. Bearing in mind its characteristic resistance to the absorption of heat, and proceeding in the opposite direction, it can be understood that the complete retention of the austenitic condition is dependent on the speed at which the heat is extracted. As this, in turn, is dictated in part by the mass, it provides the reason why there is a limiting thickness which must be observed if the steel is to be presented in its best condition.

39. It doubtless is well known that manganese steel fails badly unless it is operating under conditions that will produce a rapid increase of hardness on the working face, or faces, which in turn determines its quality of resistance to abrasion. However, if means could be devised of supplying castings to suit all sorts of conditions, then the applications of manganese steel could be widely extended.

Purpose and Use of Alloys

40. Apart from increasing the surface hardness by mechanical means, the only method offering a degree of success is to introduce an alloy which would increase the initial hardness without seriously interfering with the characteristically high resistance of the steel to impact. An alloy offering possibilities, and which at the same time would not have a great effect on the cost (which is an all-important factor) is chromium.

Table 2

ANALYSIS OF HEATS FOR WORK-HARDENING TESTS

Heat.	C %	Si %	Mn %	P %	S %
A	1.31	0.10	12.73	0.061	0.010
B	1.15	0.36	12.07	0.050	0.012
C	1.13	0.40	11.40	0.052	0.005
D	1.21	0.34	12.06	0.058	0.002
E	1.12	0.31	10.70	0.045	0.003
F	0.97	0.25	10.27	0.059	0.005
G	1.20	0.30	11.73	0.046	0.008

41. One of the authors has done a limited amount of work along those lines, and he has found that an addition of 2 per cent chromium to a normal analysis, and water toughening in the usual manner, increases the initial hardness from approximately 200 Brinell to approximately 286. At the same time, the capacity to further increased hardness by cold work was not affected.

42. It would appear, therefore, that there are possibilities, working carefully along somewhat similar lines, which will enable manganese steel to be used under circumstances where hitherto it has had only qualified success.

WORK-HARDENING CAPACITY

43. In order to test the hardening capacity of a number of casts of varying analysis, several experimental tests were carried out. Seven heats were selected of the analysis shown in Table 2.

44. A sample from each heat was taken and lightly ham-

Table 3

BRINELL HARDNESS OF SAMPLES OF ANALYSES AS SHOWN IN TABLE 2

Sample.	Normal.	Time Hammered, Minutes						
		15	25	30	40	50	55	65
A	202	247	387	444	477	477	495	532
B	187	235	387	418	477	495	512	555
C	202	247	364	402	495	512	512	532
D	192	235	351	387	444	495	532	532
E	179	228	364	387	444	477	495	512
F	217	247	418	444	495	512	532	578
G*	202	332	387	...	532	...	...	...

* Subjected to heavier hammer blows than other samples.

mered with a hand hammer for definite periods of time, and Brinell tested at each stage. In the case of Sample *G*, the hammer blows were heavier than with the others. The results obtained are shown in Table 3.

45. While this method of testing the work-hardening capacity is somewhat crude, yet an approximate indication is obtained of the qualities of one cast or of one composition against another. Reviewing the results, while it is unfortunate that none of the casts used shows a manganese content exceeding 12.73 per cent, the indications are definitely there that the lower manganese heats do not suffer by comparison with the higher.

46. A further work-hardening test was carried out by one of the writers using a pneumatic riveting hammer, operating a small tool having a working face of $1 \times 3/4$ inch. A bar of normal manganese steel, 1 inch wide by $1/2$ inch thick, was selected and subjected to hammering for periods varying from 10 to 60 seconds. It was found that the Brinell hardness increased 100 per cent after 40 seconds only, on a 1-inch length of bar.

47. This is a method which might readily be applied by manufacturers when selling castings to operate under conditions where the rate of increase in surface hardness is low.

48. It is generally accepted that the increase in hardness of manganese steel due to work arises from a precipitation of the carbides from the austenitic solution. In order to verify this, one of the Table 3 samples (*C*) was selected and a section cut from the work-hardened area. This section was polished at right angles to the hammered face and examined along the work-hardened edge.

49. Viewed at 100 magnifications, no trace of free carbide was observable, but there was exhibited an apparent crumbling of the austenitic grains, as shown in Fig. 6. As already shown, this sample was lightly hammered for 65 minutes only. It may be that continued hammering for an extended period will cause a carbide precipitation, although this has yet to be demonstrated.

DESIGN OF MANGANESE CASTINGS AND NECESSARY RISERS

50. The difficulties surrounding the manufacture of manganese steel castings have not been widely discussed, and success

has only been achieved by experience. Design plays an important part in the production of a sound casting, which is the first consideration. Therefore, the engineer responsible for the design should be familiar with the properties of manganese steel.

51. He must guard against abrupt changes in metal section, and, where possible, provide for uniform metal thicknesses throughout the casting. Ample brackets and fillets of correct proportions are contributing factors. Cored holes, etc., must be rounded to resist the stresses set up by high shrinkage. When small holes are desired in thick sections, mild-steel insets (which are later bored out) or pipes replace sand cores, and mild-steel bushings are set in hubs or bosses where a machined finish is necessary.

Importance of Correct Riser

52. Not the least important factor in the successful production of manganese steel castings is the shape and position of the risers. Until comparatively recently, in jobbing shops at least, the type and placing of risers was more or less the whim of the individual molder, who often was left to his own devices. The results of this policy often were to be seen in unsound and ineffectively fed castings, particularly in those steels of inherent high contraction.

53. It is now recognized, however, and rightly so, that there is no part of the molder's job more important than fixing the dimensions and position of the risers, and greater consideration now is given this phase than ever before.

54. In the manufacture of ingots, to insure the maximum freedom from shrinkage cavities, the large end of the hot top always is placed at the bottom. Yet how many times have we seen risers with the smallest dimensions at the point of entry?

55. There are instances, of course, when this may be unavoidable—such as in the case of very light sections; but generally, necked risers should never be permitted, as only a small percentage of the metal can find its way through the bottle-neck for feeding purposes. Even in the case of light sections it often is preferable to insure effective feeding by making the riser at the base wider than the section, thus incurring extra expense of removal rather than risking the possibility of an unsound casting.

56. An adequate riser does not necessarily mean less effec

tive recovery of finished castings. On the contrary, it may mean more in the final analysis, because it often is possible to cut down actual weight of a well-designed riser due to greater efficiency.

57. In dealing with manganese steel or any similar piping steel, it is necessary to increase the height of the riser beyond that required for mild steel. In other respects the risers may be the same.

58. There is another aspect of the riser problem to which insufficient attention is given, namely, the question of using them hot. It is obvious that the effectiveness of any riser is governed to some extent by its temperature at the time of pouring; and no riser, however well designed, can be one hundred per cent efficient if it is cold. The foundryman seeking the best results and the highest recovery will keep his risers hot and never place them on the job until the last moment.

PREPARATION OF MOLDS

59. Highly refractory, free venting, naturally bonded sands are generally used. In dry-sand work, provision for metal contraction is made by digging out pockets and filling with old sand at points where excessive resistance may be set up.

60. Such sands produce satisfactory castings, provided the teeming temperature of the metal and gating of the mold is properly controlled. Internal chilling is resorted to only in extreme cases. When internal chilling is considered necessary, crimped or waved 1/8-inch or 1/4-inch manganese-steel wire is useful, because it does not present the resistance to contraction of an equivalent weight of straight wire in the event that the chilling is overdone.

61. Experience has shown that best results, from the standpoint of appearance and structure of the steel, are obtained by teeming at the lowest temperature relative to the section of the casting, and admitting the steel at as many points as are permissible. This insures a more uniform temperature gradient throughout the cooling metal.

FETTLING OF MANGANESE-STEEL CASTINGS

62. The cutting of risers from manganese steel castings often presents difficulties. As is well known, manganese steel in the

"as cast" state is very brittle, due to the arrangement of free cementite about the grain boundaries, and often a well-directed blow with a hammer is sufficient to sever a comparatively large head. This method, however, is seldom practiced on account of the danger of fracturing the casting itself.

63. It is a debatable point whether castings should be removed from the sand, roughly fettled and then placed in the furnace while still hot, or allowed to cool slowly in the sand before proceeding with the subsequent treatment. Generally, however, the latter procedure is followed, although in either case it is not necessary to remove thoroughly all the adhering sand.

64. The removal of risers, runners, etc., by the use of the oxyacetylene torch calls for extreme care, because of the danger of local overheating, setting up stresses which may result in cracking the castings. The following methods have been tried to overcome this difficulty:

1—Castings are first heated in a furnace or upon an open fire.

2—Castings are immersed in water to the line of the proposed cut.

3—The cut is followed by a stream of water delivered by a fishtail nozzle. This last method finds general favor, being easily applied, flexible, and efficient.

DISCUSSION

ORAL DISCUSSION

JOHN HOWE HALL:¹ It is true that manganese steel has held its own to a remarkable extent in applications to which it is suited, but I believe that most of those engaged in the manufacture of alloy steels to resist wear realize that the field of manganese steel has been considerably narrowed. Today it is not used in places where it was used twenty years ago, because metallurgists have developed other steels more suited to some of these applications.

I have in mind particularly what is mentioned in paragraph 6—the

¹Technical Assistant to President, Taylor-Wharton Iron & Steel Co., High Bridge, N. J.

use of manganese steel in brick and tile machinery, for example. In this country manganese steel is no longer employed for service of that sort; it has been replaced by steels with initially higher hardness.

The increase of silicon and decrease of manganese mentioned in Table 1 is interesting to us, particularly since we do not encounter it in our own practice. We use a magnesite lining in our ladles, or a chromite lining, which I believe is almost universal American practice in manganese steel production.

Hundreds of tests show that there is virtually no change in the silicon or manganese content in pouring the steel, although in some cases we take as long as an hour to pour a heat. Apparently, with an acid-lined ladle there is quite a change in composition of the steel during the pouring.

I was struck by the description in paragraph 16 of the use of crucibles for melting ferromanganese in shops making manganese steel with a Tropenas converter. Melting with crucibles in this country died soon after 1916 and since then has been succeeded by the cupola, which is far more economical.

My attention was directed to paragraph 18 and the comparatively high carbon the authors state they obtain by the Tropenas process. In using the Tropenas converter in this country the carbon in manganese steel averages more nearly 1.15 per cent than 1.30 per cent as given in the paper.

We do not consider the method of taking samples as mentioned in paragraph 22 to be good practice for the final analysis of manganese steel or any other steel. We use the method to secure drillings from preliminary tests in the electric furnace where we need not be accurate; but for the final analysis we anneal our samples for a number of hours at 500 degs. Cent. and then drill deeply with a glass-hard drill, thus getting clean, fine drillings. This we consider much better practice.

The authors mention the desirability of keeping the carbon as low as possible without using special, high-priced, low-carbon ferromanganese; they say that in using lower carbon there is a tendency to reduce brittleness in the castings. This undoubtedly is true. In our own experience with large, complicated castings, we have found that a carbon over 1.25 per cent is dangerous and over 1.35 per cent is almost fatal. However, the danger from higher carbons is not from brittleness of the final, completed steel, but rather from a tendency to crack during heat treatment.

In presenting this paper Mr. Melmoth asked if anyone had determined the influence of phosphorus on manganese steel. We did not want to continue using low-phosphorus raw materials exclusively any longer than necessary if we could use a slightly higher phosphorus, so a number of years ago we made tests to find out how far we could go. We found that we could use phosphorus up to 0.125 per cent without any deleterious influence on the steel, but that above 0.125 there was a marked loss of strength and toughness. At 0.25 per cent phosphorus the steel became so brittle that test pieces could almost be broken over

the knee. The loss of strength was due to segregations of iron phosphide between the grains.

Heat-treatment temperatures mentioned by the authors are those used in this country. However, I note particularly the reference in paragraph 32 to the higher temperatures advocated as the result of some work by Svehnicov, who says that 1150 degs. Cent. produces greater strength and tenacity in manganese steel than do the normal heat-treating temperatures. I have tried temperatures as high as that and higher, and I disagree entirely with these findings.

In paragraph 34 the structure of the high-carbon manganese steel quenched at too low a temperature, shown in Fig. 4, is said to be "purely martensitic." I find that almost everyone who examines manganese steel and obtains a structure like that says that it is martensite. However, if the specimens are examined more carefully at higher magnifications, it will be found that the black needles are not martensite but cementite.

The limit to the thickness of manganese steel that can be heat treated successfully is partly due to the fact that cooling on the inside of a thick section is not rapid enough to give an austenitic structure. More important, however, is the fact that when very heavy sections of manganese steel are quenched, they almost invariably crack inside; the crack starts at the center and works out, and the casting breaks in service.

The figures on work-hardening powers of manganese steel, as shown in Table 2, are very interesting, especially the fact that work hardening does not seem to vary much with composition. The table shows that steels all the way from 10 per cent to nearly 13 per cent manganese work harden to about 550 Brinell. This also agrees with our own findings.

The suggestion that manganese steel castings be pre-hardened by mechanical work before being shipped has been tried out extensively in this country by several makers, including ourselves. This sounds good, but it must be remembered that hardness induced by hammering or pressing can go only to a slight depth, not over one-fourth or three-eighths inch at the most, so that in cases where the manganese steel is not hardened at all by the service, there is little to be gained by pre-hardening.

I was interested in the remarks in paragraphs 48 and 49 about trying to learn from microscopic examination what makes the steel harden when cold worked. Two or three years ago, in my Howe memorial lecture before the American Institute of Mining and Metallurgical Engineers, I published the results of some very careful work performed on manganese steel by Dr. Lucas of the Bell Telephone Laboratories and myself. Those results proved conclusively that hardening is due to the cold-worked portions of the steel transforming from austenite to martensite. Apparently that work did not reach the authors' attention.

In regard to paragraph 60 on the use of internal chills, to me internal chills are like a red rag to a bull, and in our shop I have never seen one used in a manganese steel casting. We use external chills to a large extent; the manganese steel industry uses chills more than any

other steel-casting makers. If external chills are intelligently designed and used, an internal chill should never be needed in a manganese steel casting.

The danger of cracking castings in the green state when cutting off heads with a torch is perfectly true, but a torch can be used on a casting in the heat-treated condition far more freely than was supposed a few years ago. The precautions mentioned in paragraph 64 are not required in the case of heat-treated castings.

Phosphorus in Red Brass

By R. W. PARSONS,* MANSFIELD, OHIO

Abstract

The author reports his observations on the effect of phosphorus on brass and bronze, with special reference to slight traces of approximately 0.01 to 0.02 per cent. It seemed to the author that these amounts of residual phosphorus would be considerable in semi-red brass alloys of the modified 85-5-5-5 variety having zinc in excess of 5 per cent. The alloy particularly studied had a composition of 81.5 per cent copper, 3 per cent tin, 7 per cent lead and 8.5 per cent zinc. Phosphorus as a deoxidizer is first compared with various other possible deoxidizers. Experimental work described was undertaken to determine underlying cause of excessive leak losses which resulted from the presence of greenish-colored inclusions in thin sections of valve castings. The data secured gave evidence to indicate that phosphorus in red brass actually serves as a deoxidizer in addition to making the metal fluid and protecting the molten stream during pouring. Copper, in new metal heats, is principal source of oxygen when melting is under reducing conditions, and either remelting or an addition of phosphorus is necessary to remove oxides and produce sound castings free from inclusions.

INTRODUCTION

1. At the nonferrous round table discussion of the A. F. A. held in Chicago in May, 1931, one question submitted was on the "Effect of phosphorus on brass and bronze, with special reference to slight traces of 0.01 to 0.02 per cent." It is understood that there was but little comment. As it seems to the writer that these amounts of residual phosphorus would be considerable

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in semi-red brass alloys of the modified 85-5-5-5 variety having zinc in excess of 5 per cent, it was felt that a report of such aspects of this question as have come under his observation might be of some interest.

2. It should be made clear at the outset that the alloy which the writer has in mind has the nominal composition of 81.5 per cent copper, 3 per cent tin, 7 per cent lead and 8.5 per cent zinc. Thus, it would fall within the classification as made by Thews¹* of those alloys which contain sufficient zinc so as not to require deoxidation in the molten bath but which require small quantities of phosphorus which act to prevent oxidation during the pouring period.

3. Phosphorus is rather widely used in foundry practice in the form of a phosphor-copper shot containing 10 to 15 per cent phosphorus, and in this paper the term "phosphorus" often is rather loosely applied to the phosphor-copper alloy as well as to the element.

4. Phosphorus is referred to freely in the literature as a deoxidizer for brass and bronze, and in such sections as the "Question Box" of *The Foundry* magazine and elsewhere¹ we frequently find recommended for red brass 1.5 oz. (0.1 per cent) of phosphor-copper per 100 lbs. of metal. Sometimes limits of 0.1 to 0.2 per cent are given, and occasionally considerably more is not considered detrimental.²

5. In the case of 0.1 to 0.2 per cent, which have been given as limits¹ for 10 per cent phosphor copper, this would mean that we would be adding 0.01 to 0.02 per cent phosphorus, of which considerable would be lost,³ so that the amount retained would be on the order of a few thousandths of 1 per cent. In bronzes, free from zinc or nearly so, the amount of phosphorus used often is several hundredths of one per cent.³

PHOSPHORUS AS A DEOXIDIZER³

6. Before relating the results of some practical tests made in this connection, it might be profitable to speculate to some extent as to the manner in which phosphorus functions, provided this can be done without the discussion becoming too theoretical and technical.

* Reference numbers given correspond to numbers shown in the *List of References* at the end of the paper.

Affinity for Oxygen

7. A convenient measure of the ability of a given elementary metal to deoxidize may be had from a consideration of the heat of formation of the resultant oxide. These values may be found in any of several handbooks, and texts and compilations such as Table 1⁵ have appeared previously in foundry literature.^{1, 4} The listed data on affinity, applying as they do to room temperatures, do not necessarily hold at the temperatures of the red brass melt, nor does it follow that the order of elements as given will be the same at elevated temperatures.

8. Table 1 indicates, however, that tin has a greater affinity for oxygen than has copper and, therefore, should deoxidize copper as it is generally accepted that it does. It will be noted, however, that the resultant oxide has a very high gravity as compared to the others listed, and we should not expect it to free itself from the red brass melt (which has a gravity in excess of 8.0) as readily as a lighter oxide, such as that of zinc.

9. This is one reason for the marked improvement in casting properties brought about by additions of zinc to the tin bronzes, as in the case of Navy G bronze. Since tin oxide is known to be

Table 1⁵

ABILITY OF ELEMENTARY METALS TO DEOXIDIZE

Element.	Oxide.	Heat of Formation of Oxide.		Properties of Oxide.	
		Calories per Gram Molecule.	Calories per Gram Atom of Oxygen.	Melting Point, degs. Fahr.	Specific Gravity.
Calcium	CaO	151.9	151.9	4600	3.3
Magnesium	MgO	143.9	143.9	5000	3.4
Aluminum	Al ₂ O ₃	392.6	130.8	3700	3.9
Titanium	TiO ₂	218.4	109.2	2800	4.2
Silicon	SiO ₂	191	95.5	3100	2.2
Boron	B ₂ O ₃	272.6	90.8	1070	1.8
Manganese	MnO	90.8	90.8	3000	5.1
Zinc	ZnO	84.8	84.8	3300	5.4
Phosphorus	P ₂ O ₅	365.2	73.0	Sublimes	2.4
Tin	SnO ₂	137.2	68.6	2050	6.9
Iron	FeO	65.7	65.7	2800	6.9 ?
Nickel	NiO	57.9	57.9	?	6.7
Copper	Cu ₂ O	43.8	43.8	2100	5.9

hard and is apt to dull the tools during machining,⁴ considerable phosphorus usually is added to deoxidize the tin bronzes and aid in the elimination of this objectionable oxide.

10. Aluminum and silicon, although ranking high as regards their affinity for oxygen, are not to be considered, of course, for red brass in view of their unfortunate reactions with the lead.^{2, 3, 6} Magnesium probably is not a desirable impurity in red brass.⁹ Metallic boron, if it were available, would seem a logical choice for investigation.

11. Zinc and phosphorus appear to have considerable affinity for oxygen and are good deoxidizers for red brass, with the former apparently a trifle superior. Of those listed, only these two elements have boiling points below the temperature of the red brass melt (phosphorus, 550 degs. Fahr.; zinc, 1688 degs. Fahr.). The oxidation products are sufficiently light so that they should be able to free themselves from the melt without any great difficulty.

Oxide of Phosphorus Is Light

12. It will be noted that the oxide of phosphorus is extremely light (second only to boron), and in addition it sublimes instead of melting. Apparently the deoxidizing action of zinc, which is added in such relatively large quantities, should leave the melt (to all practical purposes) free from oxides, insofar as phosphorus additions are concerned and in view of the small amounts of the

Table 2

CAPACITY OF ELEMENTS FOR OXYGEN

In forming the oxides given in Table 1:

1 oz. of Boron	takes up 2.18 oz. of Oxygen
1 oz. of Phosphorus	takes up 1.29 oz. of Oxygen
1 oz. of Silicon	takes up 1.13 oz. of Oxygen
1 oz. of Aluminum	takes up 0.886 oz. of Oxygen
1 oz. of Titanium	takes up 0.665 oz. of Oxygen
1 oz. of Magnesium	takes up 0.658 oz. of Oxygen
1 oz. of Calcium	takes up 0.400 oz. of Oxygen
1 oz. of Manganese	takes up 0.291 oz. of Oxygen
1 oz. of Iron	takes up 0.287 oz. of Oxygen
1 oz. of Nickel	takes up 0.273 oz. of Oxygen
1 oz. of Tin	takes up 0.270 oz. of Oxygen
1 oz. of Zinc	takes up 0.245 oz. of Oxygen
1 oz. of Copper	takes up 0.126 oz. of Oxygen

latter used. Why is it, then, that phosphorus is used to deoxidize red brass?

Capacity of Phosphorus for Oxygen

13. Table 2 presents the matter in a little different light in that the capacity of the various elements for oxygen is shown. Here, other things being equal, the lighter the element, the greater its capacity. We see that phosphorus is second only to boron and considerably ahead of zinc.

14. Even if the phosphorus trioxide (P_2O_3) is considered, the value still would be 0.773, which would not alter its position from a practical standpoint since silicon and aluminum are automatically eliminated as possibilities. Even though the capacity of phosphorus for oxygen is five times that of zinc, the ratio of phosphorus to zinc used in the foundry is much less than 1 to 5, so that our question is still not answered.

Action of Phosphorus in Removing Oxides

15. Just what the action of phosphorus may be certainly is debatable, although reference to some of the available theories and information may suffice to shed some light on the subject. Clearly, copper oxide should not exist in the presence of tin, nor should tin oxide be found where there is excess zinc. It may be that contradictory evidence is on record, in which case we might safely assume the presence of traces of oxides of copper on which phosphorus is known to act.

16. It has been stated⁷ that phosphorus will deoxidize the oxides of tin and zinc, provided the particle sizes are such that they come into sufficiently close contact in the temperature of the red brass melt. Elsewhere³ this is denied, and the removal of these oxides by phosphorus is held to be purely mechanical.

17. Another suggestion has been put forward⁴ to the effect that the oxides of tin and zinc are removed by the formation of a fluid phosphate slag. The same authority,⁴ after observing but little volatilization of phosphorus in the absence of oxygen, reasons that surface oxidation of the molten stream is inhibited not by an evolution of phosphorus forming a protective envelop, as has been suggested,¹ but that the oxidation products which are of the molten phosphate type furnish the protection.

18. As an additional point in connection with the oxide skin formed during pouring, we may consider the case of the oxide film on aluminum bronzes which may become folded into or rolled up in the metal during casting, unless pouring, gating and sand conditions are such as to admit the metal with a minimum of disturbance. It is this same aluminum-oxide film on aluminum-contaminated red brass that, during pouring, rolls up to form the inclusions which cause the excessive leak loss in such cases.²

19. It is fairly certain and capable of visible proof that, during pouring, the presence of phosphorus prevents the formation of an oxide film on the stream of metal. This property is of special interest in the present discussion, since the forthcoming practical tests deal with oxide inclusions that caused leakers. Whether it is felt that such inclusions are formed during the pouring of the mold or that the oxides are present prior to pouring, charged into the furnace or formed there, both suppositions doubtless are partially correct and the fact still remains phosphorus is beneficial in either event.

METHOD OF MAKING TESTS

20. The program to be described was undertaken to determine the underlying cause of excessive leak losses which resulted from the presence of greenish-colored inclusions in the thin sections of valve castings. As it was anywhere from two to six weeks or more between the pouring of the castings and their arrival at the test benches, it was extremely desirable to have some means by which the leak-loss information could be obtained immediately.

21. A foundry floor was set up on which to make the castings, and a multiple pattern of a small competition globe-valve body, with sections of such thinness that the test losses were above the average, was selected to be the basis for all tests. The castings then were poured, cleaned, ground and tested in a very short time as described below.

22. Usually ten molds (120 castings) were poured from experimentally melted metal, and in order to avoid misleading test information, a system of handling was employed so that it would be possible to determine at all times the mold (in order of pouring) from which a given casting came, as well as the position of the casting in the mold relative to the runner and sprue. The effect

on leak loss of defective molds or faulty pouring of molds thus was a known quantity.

23. Valve castings, with the center and pipe ends ground smooth, were tested in the rough by clamping a rubber-faced disk over the center end; the leakers were carefully examined to insure that shrinks or porous metal were not responsible. A large lot of rough castings which had passed the pressure test, ultimately was sent through the regular channels in order to prove that the bright dipping, reduction of wall thickness and removal of outer skin by machining were of no practical importance. The leak loss on the lot was 0.27 per cent, half of which was due to castings cracked during machining.

EXPERIMENTS WITH INDIRECT-ARC FURNACE

24. Starting with a capacity heat of all new metals in a small indirect-arc furnace, ten molds of castings were poured without phosphorus additions and the remainder of the heat poured into pigs. The gates, sprues and pigs were then remelted in the same furnace and again ten molds were cast without a phosphorus addition.

25. This procedure was continued until, at the end of the fifth remelt, there was insufficient metal for another lot. The metal all was sluggish, although less so after the fifth remelt; and the foundry scrap, although varying somewhat, was normal throughout the five lots.

Remelting Removes Oxides

26. The interesting fact was that the percentages good on the pressure test for the five groups of castings were, in order, 52.3, 70.0, 95.8, 95.8 and 97.7 per cent. Fractures through the defects showed oxide inclusions in all cases.

27. It thus was demonstrated that, by continuously subjecting prime metals to the reducing atmosphere which characterizes this type of melting equipment,¹⁰ the metal could be deoxidized almost to the point of being satisfactory without phosphorus additions.

28. It was felt that conclusive proof was obtained that phosphorus does more than merely protect the molten stream during pouring, and that phosphorus additions bring about actual deoxidation in the furnace or ladle.

Phosphorus Removes Oxides

29. New metal heats to which 0.1 per cent of phosphor copper (15 per cent phosphorus) was added gave better results (with 99 per cent of the castings good on the test) than those with 0.05 per cent (which showed 94.5 per cent good). In a production way the latter amount was ample, since a charge usually is about half remelted material. Fluid metal was obtained in either case and the residual phosphorus was a few thousandths of one per cent.

30. A heat composed entirely of scrap castings which were leakers was melted in the arc furnace and 0.1 per cent of phosphor copper added. The castings from the heat were 99 per cent good on the test, the foundry loss was 4 per cent, and the residual phosphorus was 0.004 per cent. Remelted leakers, with 25 per cent new metals and without a phosphorus addition, produced castings having an identical foundry loss but which were only 46 per cent good on the test.

31. This is further evidence that heats containing new metal, either wholly or in part, need to be deoxidized with phosphorus to produce satisfactory results. The copper ingot, which is poled only to a flat set and contains approximately 0.04 per cent oxygen⁸ in typical American wire bar, doubtless is the principal source of the oxygen in prime metal heats.

Excess Phosphorus Gives Trouble

32. Starting with an all-new-metal heat, and adding 0.1 per cent of phosphor copper to the first ladle, 0.15 per cent to the second and 0.2 per cent to the third, gave castings which were 99 per cent good on the test. Foundry losses (due to dirt) were normal in all three instances. The residual phosphorus was 0.01 per cent in the two latter cases.

33. However, when 0.2 per cent of phosphor copper was added each time and continuous remelting practiced, as in the first test mentioned, metal was produced on the fourth remelt which had no desire to remain in the ladle. The residual phosphorus at this point was 0.022 per cent and the metal was "wild" (very smoky) and active in the ladle (as if the ladle were wet).

34. The metal attacked the ladle lining, boiling up "dirt" which could not be prevented from entering the mold. Exclusive of this "poured in dirt," which left visible holes in the casting,

the leak losses were quite low; but the "dirt" loss in the foundry mounted with each remelt to 47 per cent at the point of maximum wildness.

35. Reducing the pouring temperature 100 degs. Fahr. (from 2100 degrees) after a fifth and final remelt, "tamed" the metal to normal. The castings were 100 per cent good on the test and 99 per cent good from the standpoint of "dirt," although there were a few misruns and cold shuts.

EXPERIMENTS WITH THE INDUCTION FURNACE

36. The induction melting unit lends itself very nicely to additions of phosphorus in the furnace, just before pouring, and in some circles³ this is considered desirable. If one-tenth pound is to be added to one hundred pounds of metal, half of this amount is charged into the furnace perhaps 5 minutes before pouring, and the balance is added to the ladles.

37. It was found, as has been stated previously,³ that phosphorus is eliminated rather rapidly from the metal at pouring temperature. With 0.006 per cent in the "button" (the metal left from the previous heat), 0.004 per cent was present after the heat was all molten; and, although 0.1 per cent of the phosphorus was added prior to pouring, only 0.003 per cent remained as residual phosphorus in the castings.

38. The leak loss was found to be proportional to the length of time that the phosphorus addition remained in the furnace before pouring. With 0.1 per cent added, the castings from a ladle poured 5 minutes later were 100 per cent good on the test, whereas, when the elapsed time was 10 to 15 minutes, only 89 to 97 per cent good castings were obtained.

CONCLUSIONS

39. The evidence would indicate that phosphorus in red brass actually serves as a deoxidizer, in addition to making the metal fluid and protecting the molten stream during pouring. Various theories are presented as to the mechanics of this deoxidation.

40. The copper, in new metal heats, is the principal source of oxygen when the melting is under reducing conditions, and either remelting or an addition of phosphorus is necessary to re-

move the oxides and produce sound castings free from inclusions.

41. For the alloy in question, which nominally contains 8.5 per cent zinc, the amounts of phosphor copper required are on the order of 0.05 to 0.1 per cent. Since the phosphorus is lost rather rapidly when the metal is at pouring temperature, the residual phosphorus resulting from this practice varies from 0 to 0.007 per cent.

42. In the arc furnace, when 0.2 per cent of phosphor copper is used continuously, the metal eventually becomes wild and the foundry losses may go as high as 47 per cent "dirt." The residual phosphorus at this point is in excess of 0.02 per cent.

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- ⁹ C. V. Nass, "Magnesium as Brass Deoxidizer," *The Foundry*, vol. 53, no. 13, July 1, 1925, p. 527.
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(Discussion of paper begins on next page)

DISCUSSION

ORAL DISCUSSION

H. M. ST. JOHN:¹ The more study one gives to the effect of these small percentages of so-called impurities, whether added purposely or by chance, the less one cares to make any positive or general statements with regard to their effect. My own experience, at least, has been that reliable evidence is conflicting, and I feel that the explanation is quite simple.

Foundry brass and bronze, with impurities normally present, have a very complicated makeup. A little difference in the composition of the metal—not only in the stated composition but in composition with respect to other impurities—may make a great difference in the effect of any impurity being investigated. Here is one of those cases where organized research is almost impossible; about the only thing to do is to find out what happens and explain it afterward, if possible.

As to phosphorus particularly, our own experience has sometimes been at variance with that described by Mr. Parsons. This, I believe, probably was due to some difference in conditions, perhaps a difference in composition of the metal.

In paragraph 35 Mr. Parsons refers to the fact that when the pouring temperature of the metal was dropped 100 degrees, even after the fifth remelt, the metal was tamed. We have found it absolutely necessary, using somewhat variable charges (as every foundryman must), to adjust the pouring temperature to the character of the metal, presumably due to a considerable extent to the impurities that may be present.

There is no question but that, if for any reason phosphorus is added in the amounts mentioned by Mr. Parsons, it is necessary to reduce the pouring temperature. It is barely possible that if it had been reduced 75 degrees instead of 100 degrees, the results would have been just as satisfactory and the misruns and cold shuts mentioned would have been avoided.

I have seen good metal made with the residual phosphorus in excess of 0.02 per cent. The old standard ingot specifications called for 0.05 per cent residual phosphorus as a maximum limit in ingots. I do not know whether or not that has been changed in the newer specifications, but if Mr. Parson's conclusions are correct I should think it would be almost impossible to use such ingot, or at least to add any additional phosphor-copper to the charge in which the ingot was used—that is, assuming the ingot actually approached that maximum figure. It has not been our experience that any difficulty arose as the result of residual phosphorus.

FRED L. WOLF:² As Mr. St. John says, the phosphorus was 0.05 per cent in the old specification. In the new specification for the red brass class of alloys it is 0.03 per cent.

¹ Metallurgist, Detroit Lubricator Co., Detroit.

² Chief Engineer and Technical Superintendent, Ohio Brass Co., Mansfield, Ohio.

In an ingot specification it must be remembered that one must provide for remelting. It is different from specifying a maximum for the metal in the casting. Ingot metal goes to users of all kinds of furnaces, some of which may have oxidizing atmosphere, some reducing atmosphere and some a neutral atmosphere. It was thought that the 0.03 per cent limit on the phosphorus would, on the average, best meet the situation.

In operating an induction furnace, for instance, there is an oxidizing atmosphere unless much charcoal is used on the top. In the crucible furnace the same condition prevails. In the indirect-arc type of furnace, of course, without adding air as is usually done, there is a distinctly reducing atmosphere.

Mr. St. John's method, I believe, is to use barium sulphate. It is claimed that barium sulphate provides the necessary oxygen to counteract the effect of the CO atmosphere. The 0.03 per cent phosphorus in the ingot probably is brought down in the finished casting to, on the average, the limits set by Mr. Parsons.

The author did not bring out or indicate that he had made any fluidity or runability tests—I believe the word "runability" is better than "fluidity." Has there been any experience on the zinc-containing alloys such as 85-5-5-5 without phosphorus?

R. W. PARSONS: One other point should be made regarding this series of tests in the indirect-arc furnace. When we added what we considered was excess phosphorus, at about the fifth remelt, we were adding it to metal that did not need much in the way of deoxidation, as shown by the previous tests on the effect of continuous remelting without phosphorus additions.

I should imagine that barium sulphate, which I believe has an oxidizing reaction, might neutralize some of the effects of the reducing atmosphere of the furnace so that metal melted in this way would not be as much reduced as that we obtained. More phosphorus, therefore, would be permissible.

There is an interesting table in the paper presented here by Mr. Kihlgren.* The extreme right-hand column of his Table 3 showed phosphorus analyses; I noticed several with 0.02 per cent, 0.03 per cent and 0.035 per cent. It would be interesting to get a little more information on that phase of the work, with those examples which show residual phosphorus content considerably higher than those I have described in my paper.

Insofar as runability tests are concerned, the only measure of runability we had was in the misruns obtained when the pouring temperature was reduced. These pouring temperatures, of course, carry a small factor of safety; for example, with this casting in production we got more than 10 molds to the ladle—more nearly 15 to 17. In our tests the pouring temperature was 2100 degs. Fahr., while in production it would be 2120 degs. Fahr.

As I recall it, there were something like six misruns. Six scrap castings out of 120 would give 5 per cent scrap, and I feel that such

* "Casting Properties of Nickel Bronzes," by N. B. Pilling and T. E. Kihlgren. This paper will appear in an early issue of TRANSACTIONS.

a loss would be sufficiently serious to excite the foundryman's attention and concern.

H. M. ST. JOHN: Apparently a misunderstanding exists in the minds of some as to the purpose of barium sulphate. Barium sulphate most emphatically is not used in our case to counteract the reducing atmosphere of the furnace; so far as I know, that is unnecessary. As a matter of fact, we use it rather rarely, and then only for a specific purpose.

The barium sulphate is used for its oxidizing effect only in cases where the metal charged into the furnace contains impurities which it is desired to remove by oxidation. In a furnace having an oxidizing atmosphere, the impurities are removed or reduced by the natural atmosphere of the furnace. In the indirect-arc furnace this is not true; the reducing atmosphere has little effect on the impurities, and to remove them it is necessary to oxidize them in some way. That is the one and only reason for using barium sulphate.

The point I raised in connection with ingot is this: I think it is generally believed that residual phosphorus is of no value as a deoxidizing agent. In other words, in a melting charge part of which contains considerable residual phosphorus and also elements which need to be deoxidized, it is necessary to add phosphor-copper to the charge to perform that deoxidation. One cannot expect the residual phosphorus to do any work. Offhand, from Mr. Parsons' results I should judge that, by adding phosphor-copper to a charge containing ingot having as high as 0.03 per cent residual phosphorus, wild metal would result.

R. W. PARSONS: At another session, in the discussion on testing for magnesium in aluminum, the point was made that some magnesium oxide might be obtained in the sampling. The same thing might apply here as regards sampling, so that, along with the metallic drillings, one might get a little "glob" of phosphate, which would indicate (analytically) considerable phosphorus present but which really would not mean anything.

Adding phosphorus to 0.03 residual phosphorus ingot would not make wild metal.

H. M. ST. JOHN: Do you imply that, in experiments where you continued to add phosphor-copper, building up the residual phosphorus in the remelt, you found that adding more phosphor-copper in the next remelt did result in wild metal?

R. W. PARSONS: As I remember it, at about the second remelt the residual phosphorus got as high as it ever was going to get, around 0.02 per cent. The successive remelts did not raise it any, so there was little evidence of the phosphorus building up. The phosphorus seems to be lost rather rapidly.

I would not say that if one used ingot containing 0.05 per cent phosphorus and added phosphorus, wild metal necessarily would result. I never saw anything like this except at this particular time. I had the doubtful pleasure of pouring this metal myself, and it required considerable footwork to avoid what boiled out of the ladle.

MEMBER: Paragraph 41 is confusing to me, and perhaps to others as well. Did I understand the author to say that he adds from 0.05 to 0.1 per cent phosphorus in his material?

R. W. PARSONS: Possibly I said "phosphorus" when I really meant phosphor-copper shot. That means one-tenth pound of phosphor-copper shot, containing 15 per cent phosphorus.

MEMBER: If that is shot, is the next figure, from zero to 0.007 per cent, phosphorus?

R. W. PARSONS: Yes, that is phosphorus.

T. E. KIHLGREN:³ Mr. Parsons has referred to Table 3 in the paper by Mr. Pilling and myself showing residual phosphorus contents, included in the table of analyses of mixtures used in fluidity tests. This table merely indicates that the residual phosphorus contents for each mixture were practically constant, and it has no bearing on the present question concerning the effect of phosphorus on the fluidity of red brass.

SAM TOUR:⁴ The general subject of gases in metals is a rather complicated problem. A vast amount of work must be done but it is difficult to outline any particular project. One question of importance is: "How do gases occur in metals?" Whether oxygen is present as copper-oxide or as some other type of oxide, is of importance. Mr. Parsons has brought out here that oxides, as zinc oxide, possibly should be reduced by phosphorus.

If a metal is high in oxygen and the oxygen is present as zinc oxide rather than as copper oxide, phosphorus additions might act differently. Actual oxygen determinations of heats deoxidized with phosphorus might show considerable oxygen present, and yet that oxygen might be present in combination with phosphorus and so have a decidedly different effect on the metal. The whole question of deoxidizing is complicated, and many of us are groping in the dark.

W. M. BALL, JR.:⁵ We are interested in the phosphor content, and the one thing we have trouble with is that the variable furnace atmospheres will change the amount of phosphorus which must go into the furnace. The charge also affects it. We try to keep our phosphorus at a given amount, but we are having trouble in not knowing just how much phosphorus to add to offset the amount of impurities or the oxides that are present.

In the steel industry they are able to take a sample, break it and read the silicon, manganese and carbon. I wonder if there is not some way by which we could take out a dipper, break it and see if it needs so many ounces of phosphorus.

Of course, after it is poured it changes color and grain and we can tell about the phosphorus; but then we have the bad casting and it is too late. The trick is to know how much phosphorus to put into the furnace to accomplish the necessary reducing.

³ International Nickel Co., Bayonne, N. J.

⁴ Vice-President, Lucius Pitkin, Inc., New York.

⁵ Foundry Superintendent, Edna Brass Mfg. Co., Cincinnati.

C. H. MORKEN:⁶ I have found two or three little tricks that have given fairly consistent success in governing just what Mr. Ball has mentioned. One concerns the stream of metal as it leaves the lip of the ladle.

If the proper amount of phosphorus is kept in the ladle which will just prevent stringers on the lip of the ladle, there is not likely to be any trouble. That is a fairly consistent and fairly positive measure. If there is too little phosphorus, that is, a sluggish metal due to oxidation, there will be stringers and not a good "break" over the lip. By adding the proper amount of phosphorus the metal can be brought to the point where a clean "break" will result. It will be found that the phosphorus addition needs adjustment from time to time; it will not run the same, week after week, but varies with metal conditions.

Another good indicator is the appearance of the sprue top. I happen to be a crank on the appearance of sprue tops and pay much attention to them. My experience has been that the sprue top should have a uniform, rather rough, black appearance, with a minimum of snow on it. If the phosphorus gets too high, particularly as the zinc in the alloy increases, more and more snow will appear on top of the sprues, and the edges of the sprue tops will become smooth and coppery. Almost invariably, that condition is an indication that the metal is likely to become wild.

The way in which the metal "breaks" over the lip of the ladle measures the minimum, and the appearance of the sprue tops measures the maximum. Good practice lies midway between these indicators.

E. F. HESS:⁷ We had occasion to run a series of tests to determine the action of phosphor-copper on our metal, closely paralleling the tests of Mr. Parsons, and the results checked with his.

We had been getting an increasing number of leaky pressure castings at the test bench, and on examination found the cause to be these greenish inclusions. Our one ounce of phosphor-copper per hundred pounds of metal, formerly sufficient to take care of this condition, was raised gradually to two ounces per hundred pounds, and still we found the inclusions.

I then decided to run a series of experiments, keeping all melting conditions the same except for the amount of phosphor-copper, which was to be added in amounts of one, three, and five ounces per hundred pounds of metal. The first series was run with virgin metal, and a second comparative series was run with ingot or secondary metal.

With the use of one ounce of phosphor-copper, many leakers were found, while the three ounces gave practically none. With five ounces, defects of a different nature were observed. It was not necessary to use as much phosphorus with the ingot metal as with new metals; the ingot metal showed only 0.004 per cent phosphorus.

With respect to reduction of temperature, our experience also showed that with the extra high phosphorus it was possible to pour quiet metal

⁶ Foundry Engineer, Detroit Electric Furnace Co., Detroit.

⁷ Foundry Research Director, Ohio Injector Co., Wadsworth, Ohio.

by lowering the temperature, and that while the misruns and cold shuts were numerous, those which we were able to test were non-leakers.

MEMBER: We have had some experience with the particular alloy discussed in Mr. Parsons' paper. It might be interesting to know that we have been operating a fairly large plumbing-goods foundry the past year, making great effort to keep all phosphorus out of the foundry, and we have had good results. We use no new copper; we use ingot and watch our metal closely, keeping our pouring temperature as low as we can run the castings. Our experience has been that since we have departed from phosphorus altogether, we have obtained better castings.

The Control of Hardness and Other Mold Properties

BY H. W. DIETERT,* DETROIT

Abstract

The control of the sand condition in the rammed mold is a very important connecting link between sand control of heap sand and casting defects. The first step in mold control is a knowledge of how mold hardness affects the other physical properties of the sand in the mold. An arbitrary definition of mold hardness is given and the method of testing described. The author shows how increase of clay bond affects the mold properties, and discusses the relations of these properties. He also shows the effect of sand grain sizes on the permeability and hardness.

INTRODUCTION

1. The control of the sand condition in the rammed mold is a very important connecting link between control of the heap sand and casting defects. The application of mold control in the foundry surely will increase the value of sand control.

2. Correlating casting defects with sand control figures usually requires an explanation of what happened in the mold. With this in view, it is essential to know what effect each sand property has on the action of the sand in the mold.

3. The first step in mold control may advantageously be the relation between mold hardness and the controlling sand properties such as moisture, clay bond and sand grain fineness.

4. A mold must be correctly rammed to produce a casting

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of satisfactory quality, and in the past foundrymen have placed the responsibility of correctly rammed molds entirely upon the molding machine and the molders.

5. Many defective molds are caused by a variation in the quality of the molding sand. The material presented in this paper shows how variation in sand properties affects the mold hardness.

DEFINITION OF MOLD HARDNESS AND FLOWABILITY

6. Mold hardness may be defined as the deformation in thousandths of an inch of the mold surface when supporting a load of 237 grams on a circle 0.2 inch in diameter. It is the mechanical measure of the swell produced by the above-mentioned load. An increase in mold hardness decreases swells and, consequently, strained molds.

7. Flowability of molding sand is the ability of the sand to flow under ramming energy to form a smooth, uniform surface. A sand low in flowability will have small portions of mold surface appear with voids, causing a rough casting surface.

METHOD OF TEST

8. To determine the effect of mold variables (such as moisture content, grain fineness and clay content) on mold hardness, some tests were run. The standard A. F. A. test equipment and methods were used in all tests to secure the data shown in Figs. 1, 2 and 3. An explanation of the test mold and mold hardness may prove of interest.

9. The standard A. F. A. sand specimen of 2 in. diameter and 2 in. long was used as the test mold for studying the mold hardness. In this manner, all test readings were obtained on test molds of a standardized ram, and are therefore comparable. The mold hardness readings were made on the top of specimen, bottom or pedestal end of specimen, and on the side of the specimen 1 inch from the pedestal end (face hardness).

EFFECT OF MOISTURE CONTENT ON MOLD HARDNESS

10. The moisture content of molding sand affects the mold hardness differently for various types of sand. To illustrate this, two radically different types of sand, with reference to effect of moisture content on mold hardness, are shown in Fig. 1.

11. The curves on the right-hand side of the chart show the variation of physical properties of an Ohio natural molding sand as moisture content changes. The curves on the left-hand side are those of a synthetic steel molding sand.

12. A comparison of the mold-hardness curves for the two sands will show the following facts:

(a) The mold hardness number of the steel molding sand decreases very rapidly as the moisture content increases.

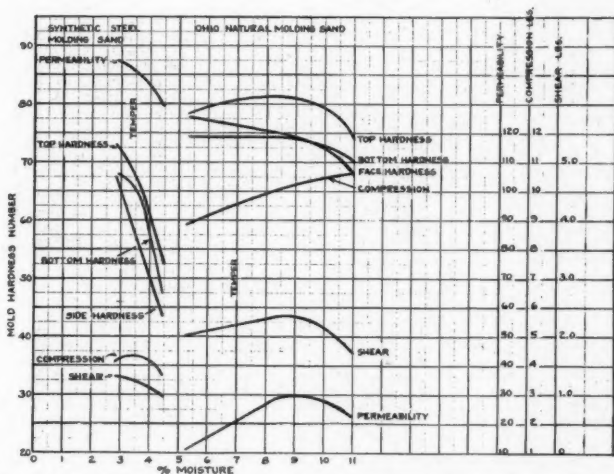


FIG. 1—COMPARISON OF MOLD PROPERTIES OF TWO SANDS WITH VARYING DEGREES OF MOISTURE CONTENT.

(b) The mold hardness number of the Ohio molding sand increases for top mold hardness up to the wet sand range and then decreases slowly the same as face and bottom mold hardness, as moisture is increased.

(c) A molding sand having mold hardness properties as shown by the synthetic sand of Fig. 1 would result in a large variation in ramming energy required to obtain uniform molds when moisture content of the sand changes slightly.

(d) Conversely, molds made from sand having the

same mold hardness properties as shown by the natural sand of Fig. 1 will not vary materially in hardness as moisture content varies.

(e) A high moisture content will reduce the mold hardness of most sands when increased sufficiently.

EFFECT OF CLAY BOND CONTENT ON MOLD HARDNESS

13. The test curves as shown in Fig. 2 were obtained by bonding A. F. A. standard sand with various percentages of an Ohio refractory clay bond, mulled and tempered to best molding

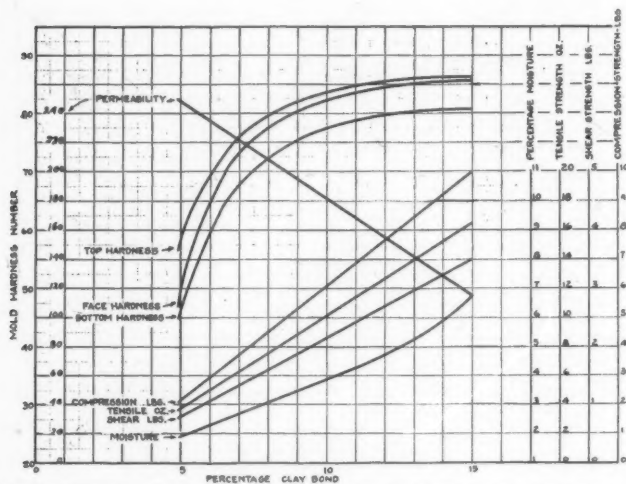


FIG. 2—EFFECTS ON PHYSICAL PROPERTIES OF MOLD WITH VARYING PERCENTAGES OF CLAY BOND.

conditions. Many practical deductions may be secured by studying the curves presented in Fig. 2. Some of these deductions are given below:

(a) The green strength tests—compression, tensile and shear—all show a straight-line relation to percentage of clay bond increase. When the clay bond percentage is increased from 5 to 15 per cent, or a 200 per cent increase, the compression

strength increased approximately 354 per cent, the tensile strength increased 331 per cent, and the shear strength shows an increase of approximately 337 per cent.

(b) The percentage of moisture required to temper the sand comes fairly close to a straight-line increase as the clay bond is increased. When the clay bond was increased from 5 to 15 per cent, or an increase of 200 per cent, the moisture was increased almost 250 per cent.

(c) Permeability of molding sand decreases rapidly as the percentage of clay bond is increased. For instance, in the example of Fig. 2, when the clay bond was increased 200 per cent, the permeability decreased from 250 to 117, or to a little over 50 per cent of the original permeability.

(d) With these relations pictured in mind as straight lines, one may visualize the mold-hardness relation to percentage of clay bond as a curve with a decided tip at low clay bond percentage.

(e) The sand with a low compression strength of 2.4 lbs. has a low face-mold hardness of 44. When the compression strength increased to 4 lbs., the side-mold hardness increased to 74. The former hardness number usually will cause swells, while the latter will give castings true to pattern. This substantiates the contention of many foundrymen that weak sand may cause swells and strains.

(f) The mold hardness of the sand with a compression strength of above 7 lbs. changes very slowly. Unfortunately, this usually is above the suitable molding range. Assuming 6 lbs. as average molding strength, one readily can see that molding sand is worked in a range where variation of clay bond or strength quickly changes the mold hardness for a given standardized ramming. This verifies the desirability of controlling the strength of molding sand at an exact figure.

EFFECT OF SAND GRAINS OR PERMEABILITY ON MOLD HARDNESS

14. The test to determine the effect of sand grain size on mold hardness was conducted as follows: Ottawa silica sand graded to sieve sizes of pan, 100, 40 and 30 mesh was mulled and bonded to 3.5 lbs. compression with bentonite, and tempered to best molding condition.

15. Physical properties of each sand mixture are shown in

Fig. 3. A number of instructive and practical conditions exist, some of which are:

(a) With the compression strength constant, it is interesting to note that the shear strength agrees quite closely with compression, with the exception that for a very fine sand grain, shear strength shows a decrease of strength. The tensile strength shows a rapid decrease as sand grain fineness increases.

(b) The permeability of the sand decreases rapidly from 30 to 100 mesh sand grains, and decreases slowly from 100 to pan material.

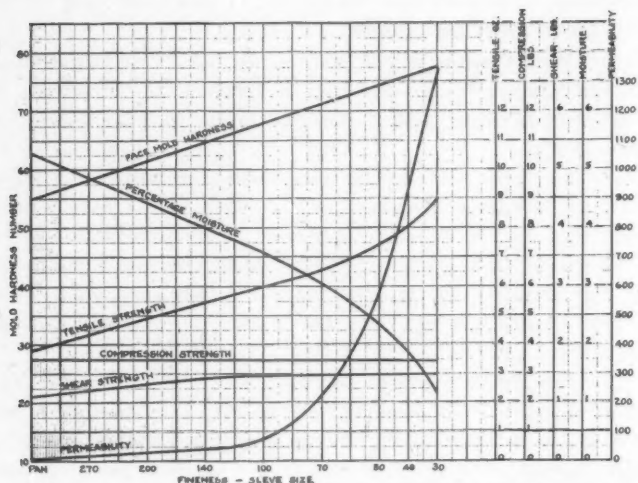


FIG. 3—EFFECTS OF SAND FINENESS ON VARIOUS MOLD PROPERTIES.

(c) The percentage of moisture required to temper the sand changes more rapidly for coarse sand grain sizes than for fine sand grain sizes.

(d) The side-mold hardness increases as a straight line as the sand grain size increases. A coarse grain sand will ram harder than a fine grain sand under equal ramming energy. Therefore, an increase in fineness, which is equivalent to a decrease in permeability, will cause a mold to ram softer and may cause an increase in casting weight, swells or strains, provided ramming energy is not increased when the fineness increases.

CONCLUSIONS

16. The facts illustrated in Figs. 1, 2 and 3 show that the hardness of molds in a foundry may be affected by other conditions than molding machines and labor. A summary of sand conditions affecting mold hardness makes this plainer.

17. Mold hardness decreases with an increase of moisture beyond the well-tempered range. For certain sands, the mold hardness decreases very rapidly with increase of moisture at any point.

18. Mold hardness increases with an increase in strength. The increase is very rapid for sand low in strength; in other words, a weak sand has a very low mold hardness.

19. Mold hardness decreases slowly with an increase in fineness or decrease of permeability.

20. Practical application of these facts is easily made. With ramming practice standardized, a soft mold may be caused by an increase of moisture or fineness. A decrease of strength to a low figure is another cause.

21. A few defects of a soft mold are overweight castings, swells, strains, poor finish, and gate swells causing scrap castings due to unequal feeding which may result in broken molds, gate breaking into casting, cuts, and washes.

22. With ramming practice standardized, a harder mold may be caused by an increase in strength or a decrease in moisture and fineness. This condition is not so fatal as softer rammed molds, providing sand is chosen correctly for casting. Common defects due to hard rammed molds are blows and scabs, providing the sand is high in strength or low in permeability.

23. Mold hardness increases with an increase in the strength of a sand when sufficient ramming energy is available. This is only natural, as a material is able to carry greater load as its strength increases. However, one must not confuse this relation with flowability. Flowability decreases when the strength of sand reaches a high strength value. The sand will not flow into restricted places. Often, voids are produced on the face of the mold surface.

24. Molding sand which is heavily tempered or wet will ram more closely together than correctly tempered sand. However, the mold hardness will be low; that is, the mold surface produced by

wet sand will not support as much load as the mold surface of correctly tempered sand.

DISCUSSION

ORAL DISCUSSION

H. W. DIETERT: Mold condition control may sound like a new subject, but that is what we have been striving to accomplish in sand control. Consequently, mold condition control is a very important connecting link between sand control and casting defects.

The application of mold control in the foundry will increase the value of sand control. In other words, to get to the root of the problem we must know what happens in the mold—whether the mold will make a good or a bad casting. Suppose sand properties change; what happens in the mold? How does the sand ram?

A. H. DIERKER:¹ What was the composition of the synthetic sand used, and how were the end points for moisture content determined? In other words, how did the author determine the range over which he tested his synthetic sand?

H. W. DIETERT: We used Ottawa banding sand for the grain structure of the synthetic sand and bonded with dextrine and clay from Missouri. We wanted to study the different types of clay. The first sand was Missouri clay bonded steel sand; we mulled it and then added our water.

The correct moisture content of molding sand can be determined beforehand to an accurate degree, of course. I feel that the most accurate method is by weight and volume. When sand is correctly tempered it will weigh the least per cubic inch.

Take a No. 6 riddle and suspend it a definite distance from the top of a gallon bucket; riddle the sand and let it fall into the gallon can. Then put the filled bucket on a sensitive scale and it will be found that when the sand is too wet or too dry, it will weigh more than when properly tempered.

The range of sands from too dry to too wet gives a sharply defined curve. On certain sands the bottom of the curve is not very sharp, but on the majority of sands the curve is quite pronounced and it is not difficult to determine the best moisture content for that sand.

A. H. DIERKER: I asked that question because the results are at variance with what we have obtained in our tests. Of course, we used a coarser sand than did Mr. Dietert; we used a regular steel molding

¹ Research Engineer, Engineering Experiment Station, Ohio State University, Columbus, Ohio.

sand, and we have found that we get a certain hardness in tempering that sand to the point where it usually would be used in a steel foundry. By increasing the moisture beyond that point the hardness of the mold decreases to a certain minimum point; beyond this point it increases.

In other words, the proper temper for the sand is below the point at which we obtain the softest mold. If the moisture is increased beyond that point, the mold will continue to get harder until it is too dry to use.

CHAIRMAN H. RIES:² Regarding the graphs of Fig. 3, showing the effect of fineness of grain on the mold properties, I understand that Mr. Dietert used bentonite as the bond. Was the same series of tests tried with bonding clay instead of bentonite?

H. W. DIETERT: We have tried clay over part of the range, and we got a complete check. The tensile strength curve had the same tendency to diverge from the compression strength curve.

² Department of Geology, Cornell University, Ithaca, N. Y.

Short-Cycle Malleableizing

By HARRY W. HIGHRITER,* CLEVELAND

Abstract

The author reviews the published data dealing with the study of the reduction of time in producing malleable iron castings from the white iron stage. The obvious advantages of reduction in the annealing period are stated to be more prompt shipment, reduced inventories, and savings in rush business. An unexpected advantage obtained, especially in the electric process, is in the reduction in depth of decarburization, favoring more rapid machining. The time required for annealing may be reduced in two ways, (1) by increasing the rate of graphitization, and (2) by bringing the commercial annealing cycle closer to the minimum required for the particular iron being annealed. The various processes developed are described and comparative data given.

1. Malleable metallurgists have long felt the desirability of reducing the time required for the manufacture of their product, and have sought means to this end. Their efforts naturally were directed into research toward more rapid malleableizing, which is by far the most time-consuming part of the process, by former methods requiring from seven to ten days.

2. This research naturally took the course of investigations of the influence (upon the time required for annealing) of the contents of a variety of chemical elements, and the efficacy of different thermal treatments. For many years the study of the mechanism of the graphitization of iron-carbon-silicon alloys has been a favorite for academic research and for the endeavors of many of the great research metallurgists and metallographists.

3. Older malleable practice required packing the castings in a material rich in iron oxide which, under heat, reacted with the carbon in the castings. The malleableizing process was, therefore, a combination of decarburization and graphitization.

4. In the decade of 1910-1920, either more or less unintentionally or through a better understanding and application of the

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metallurgical principles involved, the industry made gradual increases in the silicon content of the product and corresponding decreases in the carbon content. This gradual increase in the content of silicon, which powerfully accelerates graphitization, and the substitution of a neutral packing for the iron oxide, has made graphitization the controlling factor in the malleableizing process, with decarburization an incidental phenomenon to be controlled according to the properties which are desired in the finished castings.

5. This change in analysis, however, did not markedly reduce the annealing period, because of serious limitations in the equipment employed. It was well known that when malleableizing a few specimens of white cast iron in a laboratory muffle, much less time was needed than in a commercial furnace. This difference in time was the summation of differences in the rates of heating and of heat penetration, and of margins needed because of poor temperature distribution and control.

6. In the main, therefore, such reductions in time as have been made in the last decade and as are described in this paper, have been accomplished through application to this old process of the newer types of heat-treating equipment, or through refinements of the older forms, or by the use of smaller units capable of greater flexibility and control—all based on an ever-growing understanding of the metallurgical principles involved. As sometimes happens, the accomplishments that have been made toward the primary purpose of time-reduction have shown some unsuspected advantages and have led to new products.

Investigations on Mechanism of Graphitization

7. It is impossible to refer here to the many steps by which knowledge of the mechanism of graphitization has been accumulated, because the literature is far too voluminous. Some early experiments have been described by Bremer.^{1*} Schwartz has recorded the history of the development of malleable iron and its metallurgy,² and has presented a summary of recent progress.³

8. Kubo⁴ claimed a considerable acceleration in the rate of graphitization by the passage through the castings while at a temperature of 700 degs. Cent. or higher of an electric current,

* Reference numbers correspond to references in the Bibliography appearing at the end of this paper.

preferably alternating, having a density of 200 amps. per sq. in., and of as high frequency as possible. Prior experiments of the author, as well as subsequent efforts to confirm Kubo's observation, failed to do so.

9. Williams and Boegehold⁵ employed a relatively high silicon content (1.3 to 4.5 per cent) for reducing the time required for graphitization. Since this was predicated on the suppression of primary graphite by casting in a chill mold, the application of this method is limited to those items which are of such relatively simple design and are required in sufficient quantities as to permit being so cast.

10. Boegehold⁶ later discovered that the formation of primary graphite could be prevented, in the presence of larger amounts of silicon than usual, by the addition to the molten iron before casting of proper amounts of certain alloying elements. For sections of 2-in. (or slightly more) thickness, and with silicon contents ranging from 1.80 to 2.00 per cent, the amounts of these metals, when present singly, necessary to prevent formation of primary graphite are: Molybdenum 0.50 per cent, vanadium 0.25, nickel 1.33, and copper 0.50.

11. Because of the high silicon content of these mixtures the rate of graphitization is markedly accelerated. Presumably the molybdenum and vanadium would retard the rate somewhat and the nickel would increase it somewhat, the copper being without appreciable effect except to reduce the resulting tensile properties. In the absence of definite knowledge it is believed that extensive commercial use of this method has not been made, probably because of the cost of the required alloying metals.

12. Schwartz,⁷ and Saito and Sawamura,⁸ found that the rate of graphitization of a white cast iron was greatly increased after the castings had been previously cooled very rapidly from a temperature above A_1 , the amount of increase being dependent upon the severity of the quench. With a material as brittle as white iron, few designs can take full advantage of this process.

13. Certain elements, such as zirconium, uranium, nickel, titanium and aluminum have been found by Schwartz^{9, 10} to serve as accelerators of the graphitizing reaction, when wholly or in part replacing or supplementing the silicon content, in some cases apparently without increasing the danger of formation of primary

graphite. Since most of these elements are very much more expensive than silicon, commercial use does not appear to have been made of their advantages.

Two Methods for Reducing Annealing Time

14. The time required for annealing malleable iron may obviously be reduced in two ways, (1) by increasing the rate of graphitization, and (2) by bringing the commercial annealing cycle closer to the minimum required for the particular iron being annealed. The developments which have been described previously come under the first heading of increasing the graphitization rate. For the reasons indicated, their accomplishment of the intended purpose has been largely negated.

Divergence Between Theoretical and Actual Cycles

15. Castings of average characteristics which could be annealed in a laboratory muffle in 60 hours or less have been and still are being annealed in commercial annealing ovens of the periodic type, holding from 25 to 45 tons per charge with cycles ranging from 150 to 225 hours, divided roughly into 35 to 50 hours in coming to temperature, 45 to 65 hours at temperature, and 70 to 110 hours cooling. The use of packing which retards the penetration of heat, especially when fine; poor circulation of furnace gases because of crowding stacks of pots too closely; bad temperature distribution because of faulty flue arrangements, oven design, and localized source of heat, are some of the common causes of this wide divergence between the necessary and actual cycles.

The Minimum Cycle

16. In attempting to correct these furnace conditions to approach nearer to the minimum cycle, it is necessary to know what the minimum cycle is. This necessitates accurate knowledge of the interrelation and effect upon rate of graphitization of chemical composition (with respect to unusual elements as well as those for which analysis is commonly made), annealing temperatures, physical properties, casting practice, raw materials, and thermal history.

17. The amount of research necessary to evaluate the relationships of all these factors is enormous, as will be readily appreciated. No more than a beginning has been possible, especially

as regards the effects of casting practice, raw materials and thermal history, as well as many of the unusual chemical elements.

18. By holding these factors as uniformly as possible in conformity to good foundry practice, it is possible to work out the rates of graphitization corresponding to variations in the usual chemical elements and for a range of annealing temperatures. Hayes and his associates,^{11, 12, 13} Schwartz,^{7, 9, 10, 14, 15, 16, 17, 18} Kikuta,^{18, 19} and many others have carried on extensive research along these lines, some of which has found expression in patented annealing cycles, and other of which has not been published.

19. Hayes' research especially has led to the development of a group of proprietary, partially malleableized intermediate products possessing higher strength and lower elongation than normal malleable iron. These are known under the trade name of "Z" metals and are produced by licensees under the patents of the Industrial Furnace Corp. of Buffalo. Electrically heated car-type furnaces operated with special cycles are used.

Research on Factors Affecting Cycles

20. An admirable attempt to reconcile and supplement the published data on the relation of chemical composition, annealing temperatures and cycles and rates of graphitization, is the research which has been carried on at the Department of Engineering Research of the University of Michigan as a project sponsored by the American Gas Association. A paper reporting accomplishments to date on this project has been prepared by Prof. A. E. White and Richard Schneidewind.*

Equipment Used in Commercial Production of Malleable Iron by Short Cycles

21. We come now to a consideration of the equipment used in commercial production of malleable iron by short cycles.

General Electric Co. Electric Furnace Process.

22. A description of the electric furnace and methods developed by the General Electric Co. has been given by Valentine.²⁰ It is said that malleable iron made by these means, possessing

* The paper by Messrs. White and Schneidewind will be found on page 88 of this issue.

physical properties equal to or in excess of those regularly obtained, may be produced in a total time of 30 hours or less. Full details of the cycle employed have not been published, although this consists essentially of a rapid heating of the castings stacked without pots on cars, maintaining a sufficiently high temperature in one furnace to effect the first stage of graphitization, after which the car is transferred to a low-temperature furnace where the cooling and drawing operation is effected.

23. The castings are cooled to 1346 degs. Fahr., which is maintained for 4 hours, when a further drop of 18 degs. Fahr. is

Table 1
ELECTRIC FURNACE DATA
(*Industrial Furnace Corporation*)

Standard sizes, in tons castings per charge	1	2½	5	10	15	25
Cost complete, for single units—including excavations, foundations, transformers, labor, etc.; excluding building changes, feed-line extensions.	\$5000	\$17,500	\$24,500	\$37,500	\$47,500	\$55,000
Kw-hrs. per ton of gross charge, at full capacity	625	575	500	425	375	325
Full load demand, kw.....	60				600	

made to 1328 degs. Fahr., and this temperature maintained for 4 hours. The castings then are transferred into a cooling furnace or into the air. Data showing the cost of the method of annealing are not available.

Industrial Furnace Corp. Process.

24. The construction and operation of electric furnaces constructed by the Industrial Furnace Corp. have been described by Bremer.¹ These furnaces are of the elevated car type, similar to those made by the General Electric Co., but with the difference that all of the operations are carried out in one furnace. Table 1 lists present costs of these furnaces.

Table 2
PULVERIZED-COAL CAR-TYPE FURNACES
(Whiting Corporation)

Standard sizes, in tons castings, per charge.		9	12	15
Approximate cost complete, in- cluding pulverizer, car, foun- dations, brickwork, erecting labor.	Single Unit	\$7570	\$8415	\$9560
	Battery of 3	\$24,440	\$27,270	\$30,400

Tobata Foundry Co. Process.

25. Electric annealing furnaces operated on a patented cycle have been developed and installed by Kikuta²¹ at the Tobata Foundry Co., Tobata, Japan. The castings are heated at 1650 degs. Fahr. for about 10 hours, cooled to a temperature slightly below the critical point, and held at this temperature for 25 hours. The total time is said to be only 35 hours, and no packing materials are used. An ultimate tensile strength averaging 58,000 lbs. per sq. in., and an elongation averaging 18 per cent, are said to be obtained.

Whiting Corp. Pulverized-Coal-Fired Furnace Process.

26. The Whiting Corp. of Harvey, Ill., has developed and installed in several foundries small pulverized-coal-fired car-type furnaces. These are built in sizes of 9, 12 and 15 tons, or larger on order. These furnaces represent a lower investment than electric furnaces of comparable capacity, and very low fuel costs have been obtained, due to the efficiency of operation and the ability to reload an oven in approximately one-half hour, which preserves the heat stored in the refractories. Pots and packing materials are used.

27. It is probable, however, that these furnaces will not lend themselves to the production of the special, partially malleableized intermediate products which are being made in electric furnaces. Initial costs of these furnaces are given in Table 2.

Pit-Type Gas-Fired Furnace Process.

28. Phillips²² has described a battery of 24 small pit-type gas-fired malleableizing furnaces in use at an East St. Louis foun-

dry. At this plant the castings are packed in pots, presumably in packing. Details of the cycle of operation and cost are not available. The processes are said to be patented.

Small Oil-Fired Annealing Ovens.

29. A number of American malleable foundries have erected in their own plants small, oil-fired annealing ovens designed to hold from three to five tons of castings. The details of construction and annealing cycles vary widely with the individual plants. Pots and packing materials are used, and the reduction in time for annealing is not as great, therefore, as in the case of some of the other processes.

30. Probably the limit in small ovens is one which has been in operation for several years, holding one stand of three pots. Fuel cost naturally is very high, but this has been used for rush samples or other very small orders, the importance of prompt delivery of which outweighs cost considerations.

Miscellaneous Processes.

31. A number of other methods have been used for adapting the conventional type of periodic coal-fired furnace to shorter cycles. To some extent, this has been brought about by the reduced operating rate of most foundries during the past two years, under which the production of several days might be required to fill completely a large oven, unduly delaying deliveries. In such cases, some foundries have constructed false walls, either across the center of the oven or parallel to side walls, thus considerably reducing the capacity of the oven and correspondingly increasing the speed of heating and cooling.

32. Another foundry, which has 25-ton hand-fired ovens, has been able to reduce the cycle very markedly through the installation on two ovens of one unit pulverizer, accompanying this with a reduction of 40 per cent in the charge of the oven. The oven floor area is not reduced.

33. By distributing the remaining 15 tons of castings throughout the oven, better circulation of hot gases is provided, which permits harder firing without local overheating. The lighter charge reaches temperature more quickly and, in turn, the cooling operations can be accelerated at such stages of the cycle as

permissible. By these means the cycle has been reduced from about 180 hours to a maximum of 110 hours.

Summary of Processes.

34. The malleableizing cycles employed in the short annealing processes described are summarized in Table 3. These are largely self-explanatory. The cycle of operation of the small oil-fired oven at Plant A is unusual in the very small time allowed at soaking temperature and in the cooling schedule used.

Reducing the Soaking Period

35. It is obvious that the time required during the first stage of graphitization, the soaking period, can be reduced by using higher temperatures. However, there is a practical limit to this (at about 1750 degs. Fahr.) brought about by considerations of warpage of castings, excessive oxidation of pots where these are used, and probably higher fuel costs. Tensile properties of the product also are reduced with higher temperatures.

Cooling from Soaking Temperature

36. The advisability of saving time by a relatively rapid rate of cooling from the soaking temperature to a temperature near the critical point is exemplified in all cycles. Many foundries have found this entirely practicable in the operation of their regular long-cycle ovens. By opening dampers after firing has been stopped, they have accelerated the cooling to 20 degrees per hour or more until about 1400 degs. Fahr. has been reached, when dampers are closed and cooling retarded to the normal rate, or the fire may be relighted and cooling rate further retarded, or the temperature held constant just below the critical point, at about 1300 to 1330 degs. Fahr., for 5 to 15 hours.

37. In all of the cycles illustrated in Table 3, with the exception of the two for car-type furnaces, some further time than is indicated usually is allowed for further cooling after doors are opened to permit entrance of unloading trucks.

Temperature Control

38. In all cases of operation of short cycles, it is considered advantageous to locate thermocouples inside the pots in actual

Table 4
FURNACE COSTS AND ESTIMATED ANNEALING COSTS
BASED ON 5000 TONS ANNUAL CAPACITY

	LONG CYCLE					SHORT CYCLE				
	Pulv.-Coal-fired, Central Station.		Oil-fired		Tunnel Kiln	Electric Car-type, Pulv.-Coal-fired.		Car-type		Large Pulv.-Coal- fired, 60% Capacity.
	Hand-fired	Central Station.	6	25		Industrial Furnace Corp.	Whiting Corp.	Small Oil-fired.	Small Oil-fired, 60% Capacity.	
No. of furnaces needed	6	6	6	1		3	4	13	4	
Rated capacity per furnace, tons	25	25	25	20 tons per day		25	15	5	25	
Actual capacity per furnace, tons	25	25	25	6000 tons per year		17-22	11-14	5	15	
INVESTMENT:										
Furnaces	\$31,500	\$31,500	\$31,500	\$119,000		\$120,000	\$40,500	\$12,000	\$21,000	
Building at \$1.75 per sq. ft.	4900	4900	4800	13,100		1950	6000	2420	3030	
Fuel equipment		28,900	10,500	included			included	12,000	6000	
Total investment	36,300	65,200	46,800	132,100		121,950	46,500	26,420	30,030	
Investment per ton of capacity	7.24	13.04	9.36	22.02		24.39	9.30	5.28	6.01	
ANNEALING COSTS PER TON OF PRODUCTION										
Labor (all annealing)	\$2.90	\$2.31	\$2.10	\$1.91		\$1.50	\$2.30	\$2.10	\$2.50	
Fuel	2.20	1.50	2.40	3.43			1.00	2.40	1.50	
Power, 1 ct. per kw. hr.		0.10				4.25	0.07	0.10 steam	0.10	
Pots	2.65	2.00	2.94	1.71		0.75	1.80	2.50	1.80	
Maintenance	0.81	0.81	1.71	0.08		0.50	1.00	1.00	0.95	
DEPRECIATION:										
Furnaces, 7½%	0.47	0.47	0.47	1.49		1.80	0.61	0.18	0.32	
Building, 3%	0.03	0.03	0.03	0.06		0.02	0.04	0.02	0.02	
Fuel equipment, 12½%		0.72	0.16 (7½%)					0.18 (7½%)	0.12	
Interest on investment, 8%	0.44	0.79	0.57	1.32		1.49	0.56	0.32	0.36	
TOTAL	\$9.50	\$8.73	\$10.38	\$10.00		\$10.31	\$7.38	\$8.80	\$7.67	
No. of plants averaged	25	5-7	6-9	1		1	1	1	1	

contact with castings, and in more than one location, for a more accurate indication of the actual casting temperatures. The length of time required for penetration of heat through pots is not constant, but depends upon the character of the castings as well as upon the packing material. As a consequence, thermocouples located in the oven atmosphere outside pots may not indicate the true temperature of the castings even when allowance is made for an average lag.

Costs

39. An item of especial interest in considering the subject is that of cost, both of the initial investment as well as for operation. In Table 4 an attempt has been made to present the costs of short-cycle malleableizing with four different types of equipment in comparison with four conventional types of long-cycle equipment.

40. Data for the long-cycle operations in the Table 4 were compiled as averages of actual costs in a considerable number of malleable foundries during 1929. An attempt has been made to scale these costs down to present levels by reducing labor 15 per cent, materials 10 per cent, and investment $12\frac{1}{2}$ per cent from the 1929 level. In order that the comparisons may be on an equivalent basis, the installations have been based on an annual capacity of 5,000 tons of castings.

41. In the case of equipment for short-cycle malleableizing, allowance has been made for the fact that variations in the character of work frequently will reduce the capacity of a furnace from its rated value. Thus, in the case of one electric furnace installation, three 25-ton furnaces for several months have averaged loads between 17 and 22 tons. One 15-ton pulverized-coal car-type furnace, operated on heavy-type castings, holds from 11 to 14 tons.

42. Installation costs for the electric and pulverized-coal-fired car-type ovens, given in Tables 1, 2 and 3, are based on present quotations of the manufacturers. The investment for the small oil-fired ovens is largely our own estimate.

43. It cannot be emphasized too strongly that the data given in this table should be considered as an estimate only. In all cases where it has been possible, the operating costs are based

Table 5
COMPARATIVE TENSILE PROPERTIES

Type of Short Annealing Equipment	Electric General Elec- tric Co. ²⁰	Electric Industrial Furnace Corp. Equipment	Electric Tobata Foundry Kikuta ²¹	Small Oil-Fired	Large, Pulv.— Coal-Fired, 60% Capacity
No. of Tests	13				
Ultimate Strength, lbs. per sq. in.					
Reg. Anneal	53,000	53,454		56,000	54,000
Short Anneal	56,000	54,025	58,000	54,000	54,000
Difference	+3,000	+571		-2,000	0
Yield Point, lbs. per sq. in.					
Reg. Anneal	34,800			37,000	35,500
Short Anneal	34,300			36,000	35,500
Difference	-500			-1,000	0
Elongation, %					
Reg. Anneal	15.0	20.9		24.0	20.0
Short Anneal	15.0	18.1	18.0	20.0	20.0
Difference	0.0	-2.8		-4.0	0.0

upon actual results, adjusted as seemed necessary for a proper comparison. It is felt that the items of cost are explained in sufficient detail in the table to permit readjustment of the estimates of investment and cost to such other basis of annual capacity as may be desired and for local plant conditions.

Comparison of Physical Properties

44. It has been mentioned that the time required for malleableizing can be reduced by the use of higher temperatures at some sacrifice of physical properties of the product. A consideration of the tensile values obtained by short-cycle malleableizing as compared with the values for duplicate irons annealed by the longer methods, is, therefore, of interest. Data on this subject are meager, but such as have been available to the author are given in Table 5.

45. It is evident that there is no marked trend, in some cases the short cycles producing higher ultimate strengths and in others lower, although there is a tendency toward lower elongation with the rapidly annealed product. The reason for these variations in the results of the different short-cycle methods may perhaps be found in the fact that some of these processes employ high temperatures, whereas others accomplish reductions in time

by the elimination of those periods of slow cooling which, in the long processes, add little or nothing to physical properties. The conclusion is justified, however, that it is practicable to reduce annealing time very materially without serious sacrifice of physical properties.

Advantages of Reductions in Annealing Time

46. The obvious advantages of reduction in the annealing period are, of course, more prompt shipments, reduced inventory, and the occasional saving of rush business which might otherwise go to other metals. An unexpected advantage obtained—and this is true especially of the electric process—is in the reduction in the depth of decarburization of castings, which is not only favorable in itself to more rapid machining but is less conducive to the formation of pearlitic framed castings, and thus tends further to eliminate machining difficulty.

47. H. O. Breaker, president of the Industrial Furnace Corp., reports²³ that in one test 15,000 electrically annealed castings were machined per tool grinding, as compared with 9000 regularly annealed castings per tool grinding. It has been the experience of the author that threading operations (and especially internal threading) are rendered difficult if the carbon content of the layer in which machining is done has been lowered by decarburization much below 1.25 per cent.

48. The factors which influence decarburization most strongly are the oxygen content of packing, the tightness of sealing of pots, the temperatures involved, and especially the length of time at high temperatures. By reduction of time and by generally closer control, decarburization can be reduced.

Standardization versus Diversification of Product

49. For many years the malleable industry has concentrated efforts toward the improvement of quality, which has been of tremendous value to the industry although tending toward standardization of the product. A continuation of this tendency may become increasingly injurious from a sales standpoint, inasmuch as some customers wish to have a casting possessing high strength and great resistance to shock, whereas others desire maximum machinability without a requirement for high physical properties.

50. The present trend toward short-cycle malleableizing in small units, capable of a high degree of control, is a step in the direction of a diversification and specialization toward a wider range of malleable irons, each of which is specifically adapted to the intended use. With the constantly growing competition and the new developments of other metals, this step toward widening the applicability of malleable castings should have the interest and study of the malleable industry.

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⁵ U. S. Patent, No. 1,591,598.

⁶ U. S. Patent, No. 1,707,753.

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¹⁰ U. S. Patent, No. 1,640,674.

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¹⁴ H. A. Schwartz and G. M. Guiler, *Chemical Elements Inhibiting Graphitization*. TRANSACTIONS A. F. A. (1925), vol. 33, pp. 639-645.

¹⁵ H. A. Schwartz, "Graphitization in the Presence of Nickel," *Transactions A. S. S. T.*, vol. 15, 1929, pp. 957-966.

¹⁶ H. A. Schwartz, "Graphitization at Constant Temperature," *Transactions A. S. S. T.*, vol. 9, 1926, pp. 883-906.

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(Discussion of the preceding paper is combined with that of the following paper, and will be found on page 117.)

The Metallurgy of Malleabilization

By A. E. WHITE* AND R. SCHNEIDEWIND,† ANN ARBOR, MICH.

Abstract

Reducing time for malleableizing can be accomplished (1) by better furnace design and atmosphere control, and (2) by increasing the rate of graphitization. The factors which influence the graphitization rate are the raw materials used, melting and casting conditions, special elements and impurities, carbon and silicon contents, temperature of annealing, and temperature control and atmosphere. The course of graphitization of a typical white iron is followed chemically and metallographically. It is pointed out that from the theoretical angle three things affect the rate of malleabilization: (1) the stability of the carbide, (2) the ease of graphite nucleus formation, and (3) the mobility of the carbon atom. The various practical factors affecting malleabilization are discussed. As the temperature of soaking is increased, the time for first-stage graphitization decreases logarithmically; temperature affects second-stage graphitization similarly. The soaking temperature determines the size and distribution of the graphite particles; a high temperature favors the formation of small, numerous, elongated carbon particles; a low temperature favors fewer, large, rounded particles. Silicon raises the critical point, thus permitting higher temperatures for second-stage annealing; it lowers the eutectoid composition. Other conditions being equal, as silicon is increased, the time for malleabilization decreases logarithmically. High silicon favors the formation of numerous small graphite particles; low silicon, few and large graphite particles. Carbon does not greatly affect annealing time. By using a properly controlled atmosphere, packing material may be eliminated without causing scaling, decarburization or formation of pearlite rim. The atmosphere has no direct effect on annealing time.

1. The ultimate goal of many researches on malleabilization is to determine the conditions under which the process can be carried out in shorter time. However, before any intelligent discussion of short-cycle annealing can be entered into, it is well to

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have clearly in mind the metallurgical changes which occur when white iron is transformed into malleable iron.

2. It is a fallacy to assume that short-cycle iron is a material distinct from ordinary malleable iron; its difference is merely a matter of degree. The same metallurgical laws must fit all grades of iron.

3. There are two general ways of reducing the malleableizing cycle. First, through better furnace design and atmosphere control, the time for bringing to heat and for cooling can be reduced and the use of packing material can be eliminated. Second, the rate of graphitization of the white iron can be increased.

4. The factors which affect the malleableizing rate are as follows:

- (a) Raw materials.
- (b) Melting and casting conditions.
- (c) Special elements and impurities.
- (d) Carbon content.
- (e) Silicon content.
- (f) Temperature of annealing and temperature control.
- (g) Atmosphere.

5. The work done to date at the University of Michigan, sponsored by the Committee on Industrial Gas Research of the American Gas Association, has been confined to a study of the last four factors, which are discussed in this paper.

EXPERIMENTAL EQUIPMENT

6. The apparatus necessary for conducting this study consisted of a gas-fired furnace, temperature-control equipment, a muffle, fixtures for holding the specimens, and apparatus for controlling the atmosphere within the muffle.

The Furnace.

7. The furnace, constructed of silica brick, was made 40 in. long, 30 in. wide, and 40 in. high inside dimensions, with a combustion chamber built on at each end. Baffles were placed in front of the burners 10 in. from each end wall so that a central heating zone 20 in. square was made.

8. The gases were completely burned before rising over the baffles so that no flames came within the central compartment which contained the muffle. The gases were drawn downward and out through a flue at the bottom of this compartment.

9. The top of the furnace was made of two special firebricks $30 \times 15 \times 4$ in. The opening thus left was used for charging and unloading. This opening was covered during operation by several large-sized firebricks which were chipped out in order to permit the thermocouples and atmosphere pipes to be inserted. Fig. 1 shows the furnace.

Temperature-Control Equipment.

10. Temperature control was effected by the use of an instrument manufactured by the Wilson-Macaulen Co., shown in Fig.

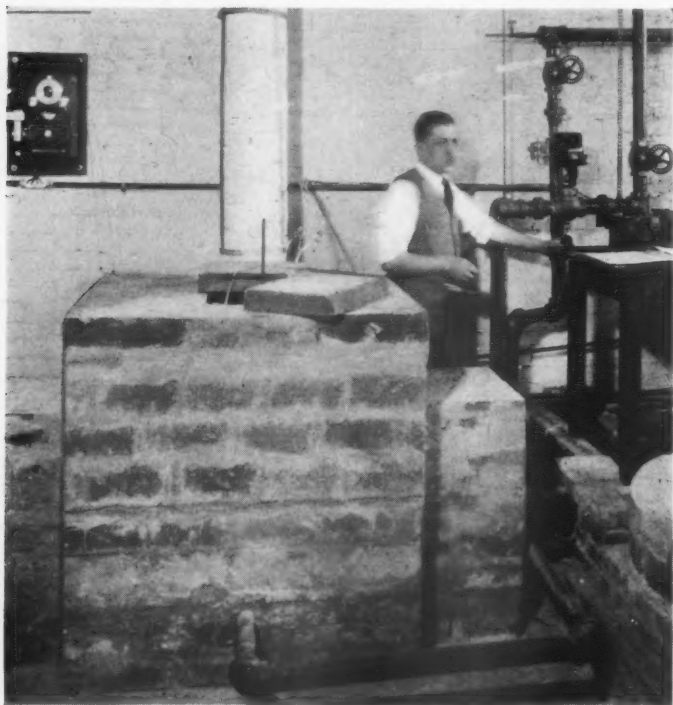


FIG. 1—THE FURNACE.

1. The controller mounted on the wall and seen in the upper left of the picture operates the motorized valves shown in center right. The temperature, measured by a thermocouple placed $1\frac{1}{2}$ in. from the outside of the muffle and a few inches from the exit flue, actuates the controller, which in turn operates a motorized valve which controls the supply of the gas-air mixture.

11. There are maximum and minimum settings for both the gas and air supplies. It has been possible to maintain the temperature within the muffle within ± 5 degs. Fahr. over long periods. During the peak-load hours a slight manual adjustment sometimes becomes necessary due to the fluctuation of the gas pressure in the line.

12. The temperature in the muffle at a point corresponding to the lower end of the test specimens proved at all times to be within 2 degs. Fahr. of that at a point corresponding to the upper end of the specimens. During each run the temperature within the muffle was measured by means of two thermocouples placed at opposite sides of the muffle.

Muffle.

13. The muffle itself consisted of a 20-in. length of cast iron pipe of 8-in. diameter, with a bottom welded on. Cast iron was chosen because it resists oxidation fairly well, because it is inexpensive and because replacements can be made at a much lower cost than if the muffle were made of KA2 or similar material.

14. The cover was made of heavy-gage sheet steel with a handle and holes to admit thermocouples and pipes for the atmosphere. The muffle, cover, thermocouple tubes, and atmosphere tube are shown in Fig. 2-A.

Fixtures.

15. Twelve specimens were held at one time in a cage, shown in Fig. 2-B. Two extra compartments were provided to hold thermocouple tubes. When filled, the cage was lowered halfway down in the muffle, where it rested upon firebricks.

Atmosphere Control.

16. The atmosphere inside of the muffle was obtained by burning a mixture of gas and air below the fixture containing the

specimens. The flame was too small to add appreciably to the heat, but it was large enough to fill the muffle completely every fifteen minutes with the products of combustion.

17. As first designed, compressed air and gas were led through flowmeters and conducted through a T-tube into a single $\frac{1}{4}$ -inch pipe which was inserted through the top of the muffle. It was found that at 1700 and 1800 degs. Fahr., cracking of the gas took place so rapidly that the tube became plugged with carbon within a few hours. A $\frac{1}{2}$ -inch pipe next was used, which proved satisfactory since plugging of a tube of this size required from 5 to 10 hours or longer.

18. The composition of the atmosphere was controlled by

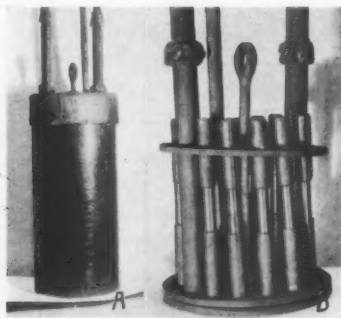


FIG. 2—A: THE MUFFLE. B: SPECIMENS AND HOLDER.

chemical analysis. From time to time samples of gas were withdrawn from the muffle into an Orsat apparatus and analyzed for carbon dioxide, carbon monoxide and oxygen. No oxygen was found in any of the runs made in this study.

19. According to the findings of Jominy and Murphy,^{1*} no scaling can take place at 1800 degs. Fahr. when the ratio of carbon dioxide to carbon monoxide (CO_2/CO) is 0.45 or less. At lower temperatures a little more carbon dioxide is permissible.

20. Since the specimens were not packed, and since scaling would make the process worthless, a CO_2/CO ratio of 0.45 was used as standard. Other ratios were used in some runs in order

* Reference numbers correspond to references listed in the Bibliography appearing at the end of this paper.

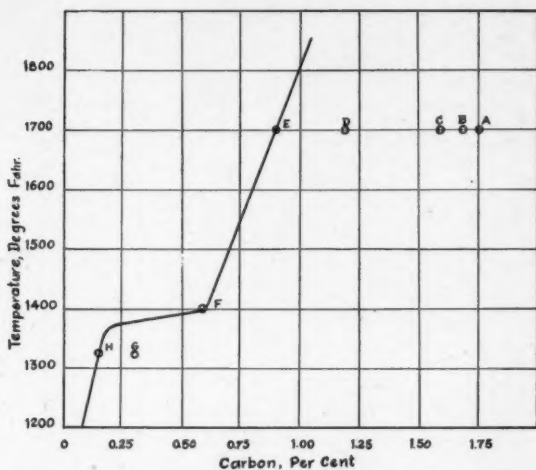


FIG. 3—MODIFIED IRON-CARBON DIAGRAM FOR IRON WITH 1.25 PER CENT SILICON.

to investigate the effect of the atmosphere on the rate of malleabilization.

THE METALLURGY OF MALLEABILIZATION

21. The iron-carbon diagram must be used as the basis of any discussion of the mechanism by which white iron is converted into malleable iron. The conventional diagram is not very helpful, since it is based upon silicon-free material in which cementite, austenite, pearlite and ferrite are stable phases at different temperatures.

22. A partial diagram applicable to malleable iron, obtained by experiment on an iron containing 1.25 per cent silicon, will be used as an example and is shown in Fig. 3. In the modified diagram, graphite rather than cementite is a stable phase. Diminishing solubility of carbon in austenite is indicated from 1800 degs. Fahr. down to the critical range, when a marked decrease in solubility takes place.

23. If a carbon content of 1.75 per cent and an initial soaking temperature of 1700 degs. Fahr. are assumed for sake of illustration, this point can be marked in the diagram of Fig. 3 as the starting point, A. Figs. 4-A and 6-A show the structure of this iron at 100 and at 1000 diameters, in the condition "as cast."

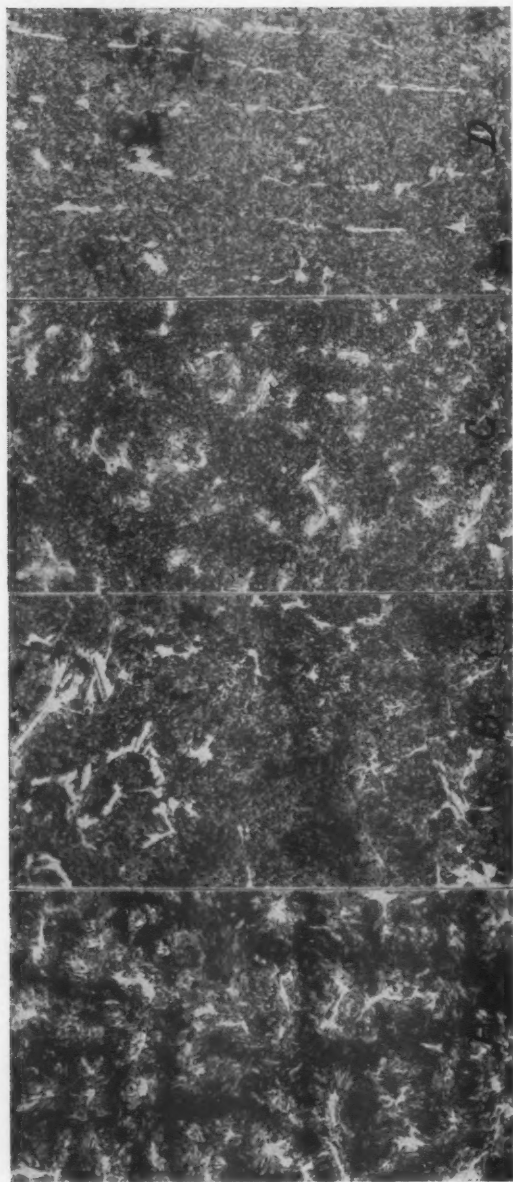


FIG. 4—A: WHITE IRON; ETCHED IN 4 PER CENT NITAL. B: HEATED 2 MINUTES AT 1700 DEGS. FAHR.; ETCHED. C: HEATED 10 MINUTES AT 1700 DEGS. FAHR.; ETCHED. D: HEATED 30 MINUTES AT 1700 DEGS. FAHR., ETCHED. ALL SPECIMENS X100.

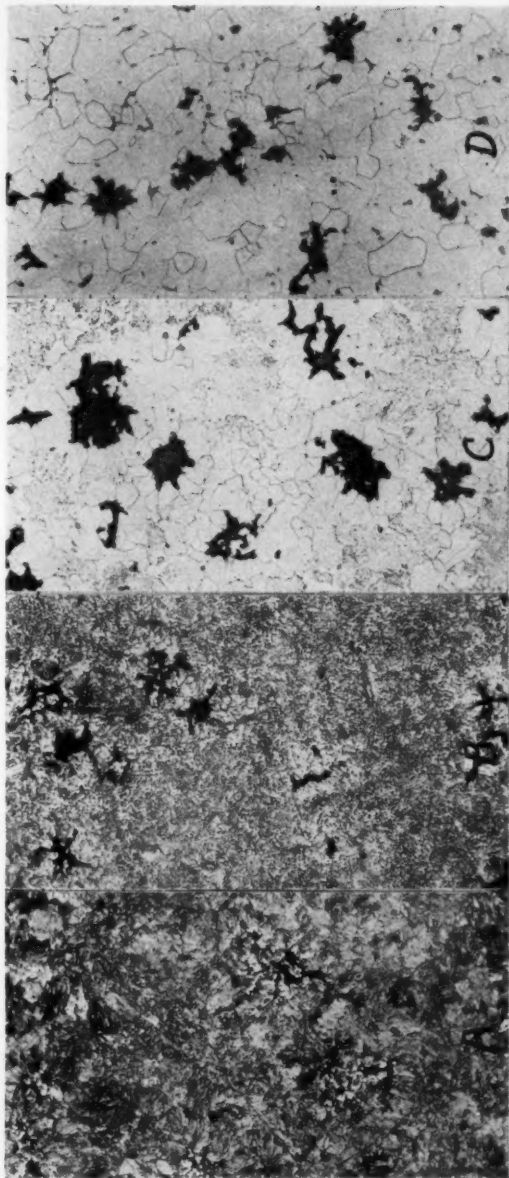


FIG. 5—A: HEATED TO EQUILIBRIUM AT 1700 DEGS. FAHR. AND COOLED TO MAINTAIN EQUILIBRIUM TO 1400 DEGS. FAHR. C: HEATED TO EQUILIBRIUM AT ALL TEMPERATURES ABOVE THE CRITICAL, 15 HOURS AT 1325 DEGS. FAHR. D: COMPLETE MALLEABILIZATION; HEATED 20 HOURS AT 1325 DEGS. FAHR. ALL SPECIMENS ETCHED, X100.

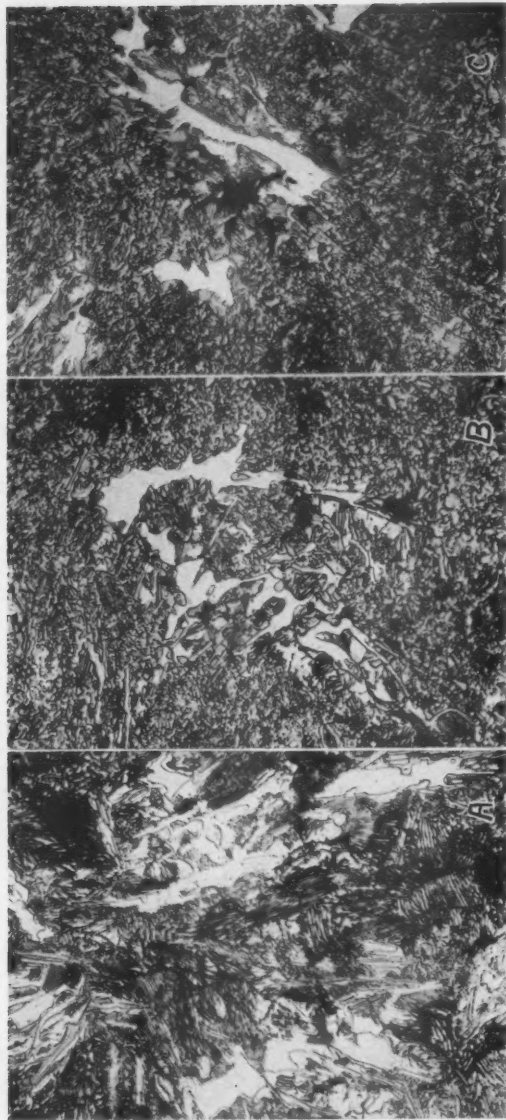


FIG. 6—A: WHITE IRON; ETCHED IN 4 PER CENT NITAL. B: HEATED 2 MINUTES AT 1700 DEGS. FAHR.; ETCHED. C: HEATED 10 MINUTES AT 1700 DEGS. FAHR.; ETCHED. ALL SPECIMENS, X1000. (REDUCED TO ONE-HALF SIZE IN PRINTING.)

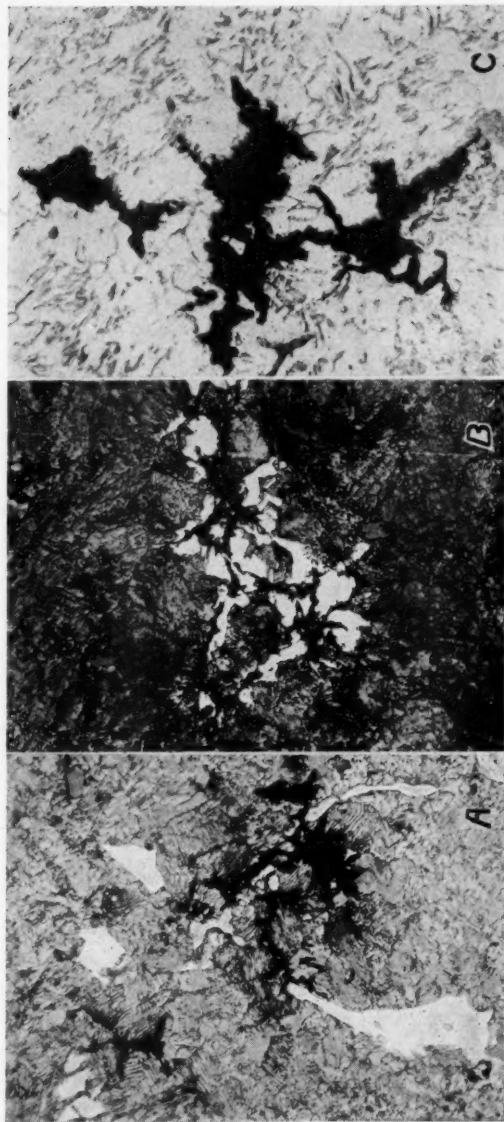


FIG. 7—A: HEATED 30 MINUTES AT 1700 DEGS. FAHR. B: HEATED TO EQUILIBRIUM AT 1700 DEGS. FAHR. C: HEATED TO EQUILIBRIUM AT 1700 DEGS. FAHR., AND COOLED TO MAINTAIN EQUILIBRIUM TO 1400 DEGS. FAHR. ALL SPECIMENS ETCHED, X1000. (REDUCED TO ONE-HALF SIZE IN PRINTING.)

24. The latter illustration indicates clearly that it is composed principally of pearlite with free cementite at the grain boundaries. The massive carbide may assume the network structure illustrated or may exist in dendritic grain-boundary form, depending upon local conditions of solidification of the melt. The unevenness of tone of the matrix shown at 100 diameters indicates a cored grain; that is, the carbon content of the pearlite is not uniformly of eutectoid composition.

25. At the first moment at heat (1700 degs. Fahr.), the austenite formed from the pearlite tends to become uniform in composition. The carbon will be in two forms—0.83 per cent will be in solid solution in austenite; the remainder, 0.92 per cent, will be combined as massive cementite. Nuclei of graphitization are soon formed.

26. The course of malleabilization will be followed chemically and metallographically in air-quenched specimens. Figs. 4-B and 6-B show the material after 2 minutes at 1700 degs. Fahr.; the time to come to heat was 15 minutes. It is evident that the pearlite is quite uniform. A small graphite particle can be seen to have formed at a boundary between the pearlite (which of course was austenite at 1700 degs. Fahr.) and the cementite. The distribution of carbon is now 0.07 per cent as graphite, 0.83 per cent as austenite, and 0.85 per cent as free cementite.

27. After various longer periods at temperature, it is apparent that the size of the graphite particles increases at the expense of the cementite. In the case of the iron under consideration, graphitization becomes progressively slower until after about three hours the free cementite has disappeared and equilibrium is reached; continued heating at this temperature produces no further graphitization. The distribution of carbon is now 0.92 per cent as graphite, 0.83 per cent as austenite, and zero per cent as free cementite.

28. Figs. 4-C, 6-C, 4-D, 7-A, 5-A and 7-B show this progress at 100 and at 1000 diameters. These various steps are marked as points A to E in Fig. 3. The per cent of carbon to the left of the equilibrium line exists in solid solution in austenite; that between the line and the point, as cementite; that to the right of the point, as graphite.

29. The graphitization of cementite carbon, or the so-called "first stage of graphitization," is now completed. The average

graphite size can be seen to increase. Graphitization evidently starts as a point which later grows and assumes a crab-like shape. It is to be noted that graphitization always takes place at a cementite-austenite interface.

30. The exact mechanism for graphitization has not yet been demonstrated conclusively. It would seem, however, that austenite has the ability to form a super-saturated solution of carbon which is brought to saturation at such points as can act as centers or nuclei of graphitization. The continuation of the process to equilibrium then can be explained on the basis of further solution of carbon or cementite, migration of the carbon atoms, and final deposition as graphite. This hypothesis is borne out by work

Table 1
DISTRIBUTION OF CARBON DURING MALLEABILIZATION

Point.	Graphite, Per Cent.	Austenite or Pearlite Carbon, Per Cent.	Cementite Carbon Per Cent.	Total Combined Carbon, Per Cent.
A	0.0	0.83	0.92	1.75
B	0.08	0.83	0.85	1.68
C	0.14	0.83	0.76	1.59
D	0.60	0.83	0.35	1.18
E	0.92	0.83	0.0	0.82
F	1.13	0.62	0.0	0.62
G	1.48	0.27	0.0	0.27
H	1.67	0.08	0.0	0.08

which indicates that the rate of graphitization at constant temperature follows the same law which governs the crystallization of salts from super-saturated aqueous solutions.

31. The temperature then is reduced to a point near the critical, at 1400 degs. Fahr., for example, and marked *F* in Fig. 3. Since there is diminishing solubility of carbon in austenite with decreasing temperature, namely, 0.83 per cent at 1700 degs. Fahr., and 0.62 per cent at 1400 degs. Fahr., about 0.2 per cent of carbon has to be expelled in the process of cooling.

32. If cooling is too rapid, the excess carbon either may form pro-eutectoid cementite in the grain boundaries or may remain, forming a supercooled austenite; if the cooling is done sufficiently slowly, the excess carbon is deposited as graphite on the graphite nuclei. This latter process could be termed the graphitization of

austenite carbon or the "intermediate state of graphitization." Figs. 5-B and 7-C show the structure of the iron, air-cooled after reaching this state, at 100 and 1000 diameters.

33. When the temperature is further lowered below the critical range—for example, to 1325 degs. Fahr.—the austenite is transformed to pearlite. The combined carbon exists in the form of cementite lamellae. In some irons these lamellae spheroidize readily; in others, the lamellae persist.

34. Graphitization now takes place until the solubility conditions for this temperature are reached. Figs. 5-C and 8 show (at 100 and 1000 diameters, respectively) the structure of an iron

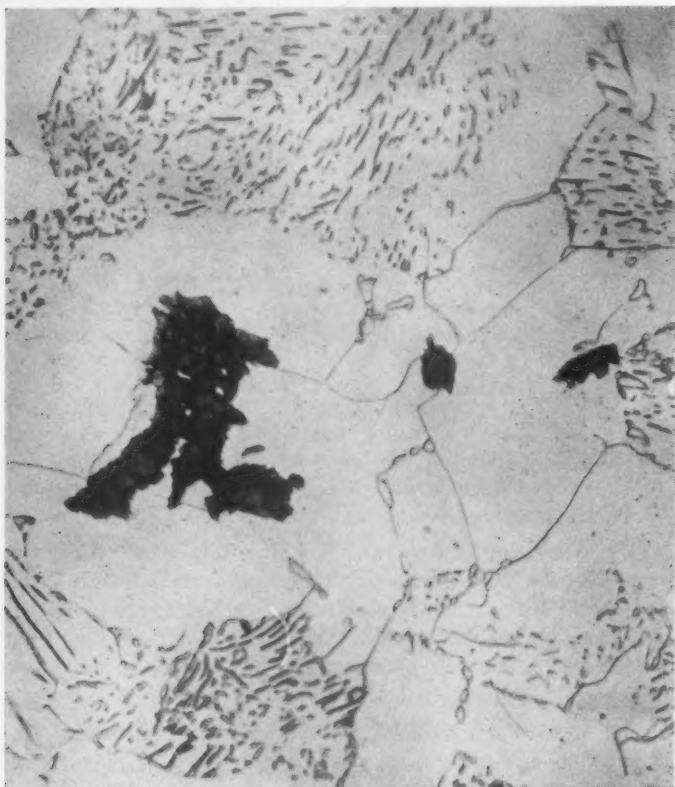


FIG. 8—HEATED TO EQUILIBRIUM AT ALL TEMPERATURES ABOVE THE CRITICAL, 15 HOURS AT 1325 DEGS. FAHR. ETCHED X1000. (REDUCED TO TWO-THIRDS SIZE IN PRINTING.)

in which this graphitization of pearlite carbon, or "the second stage of graphitization," is partial.

35. Figs. 5-D and 9 show malleabilization completed. The mechanism seems to be that the carbide particles decompose, the carbon going into an unstable solution in *alpha* iron and migrating to the graphite nuclei, where it is deposited. These stages are marked in Fig. 3 as points *G* and *H*. The distribution of the carbon is summarized in Table 1 for convenience.

36. A new method of polishing, developed at the University of Michigan and used in the preparation of these specimens for metallographic examination, does not fragment and tear out the



FIG. 9—COMPLETE MALLEABILIZATION. HEATED 20 HOURS AT 1325 DEGS. FAHR. ETCHED, X1000. (REDUCED TO TWO-THIRDS SIZE IN PRINTING.)

graphite. For this reason their boundaries and the true shape, size and color are retained.

37. Malleabilization has been discussed thus far as a process of solution of carbon to super-saturation, migration or diffusion, and deposition at certain favored locations which act as nuclei. Theoretically, then, the rate of graphitization must depend largely upon two factors, (a) the mobility of the carbon atoms and (b) the inherent ability of the iron to form graphite nuclei.

38. The atomic mobility governs the rate at which carbon atoms in the locally super-saturated austenite can travel or diffuse until they reach centers of graphitization. The facility with which these centers or nuclei are formed probably is intrinsic in the iron and is to a large extent inherited from the raw materials and also is affected by the process of melting and casting.

39. Many nuclei mean shorter distances between graphitization centers, and hence, a shorter path for the carbon atoms to diffuse through the austenite. Any set of conditions which favors nucleus formation or increases the mobility of the carbon atom should, by this reasoning, increase the rate of malleabilization. Elements which can combine with the constituents of white iron to stabilize the carbide, form thin obstructions at the grain boundaries or increase the grain size, by the same token should slow down graphitization.

PHYSICAL PROPERTIES

40. Aside from the changes in microstructure and chemical composition just demonstrated, significant changes in physical properties are brought about by malleabilization. White cast irons have a tensile strength in excess of 80,000 lbs. per sq. in. and a zero elongation. The hardness is about 350 Brinell. After malleabilization the tensile strength is about 50,000 to 55,000 lbs. per sq. in., the elongation 15 per cent or over, and the Brinell hardness in the neighborhood of 125.

41. It is evident, from a consideration of the nature of malleable iron, that the physical properties in the ideal case can approach but never exceed those of a very low carbon, annealed steel of the same silicon content. Fig. 10 shows graphically the properties of low-carbon silicon steels in the annealed condition obtained by Hadfield.²

42. A comparison of the values for a one per cent silicon

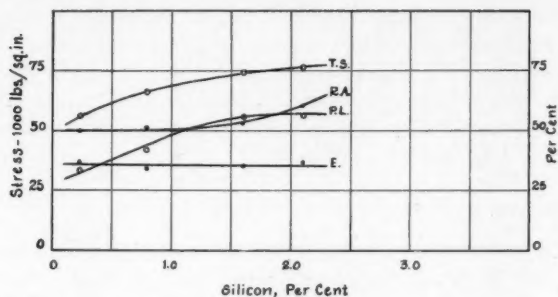


FIG. 10.—TENSILE PROPERTIES OF ANNEALED LOW-CARBON SILICON STEEL. (HADFIELD)

steel and of an average malleable iron tends to show that the graphite resulting from an initial total carbon content of about 2.5 per cent brings about a reduction of about 15 to 20 per cent in tensile strength and proportional limit and a reduction of about 50 per cent in elongation. One would expect better physical properties in a malleable iron containing less carbon.

43. A higher silicon content should also increase materially the strength without impairing the ductility. This interpretation of Fig. 10 is borne out by results of tests of irons containing from 1.6 to 1.9 per cent silicon and 1.25 to 1.5 per cent carbon which showed more than 70,000 lbs. per sq. in. tensile strength and elongations of 17.5 per cent and over.

44. There is a danger in high-silicon alloys of low impact values which may not be revealed in the tensile strength data. In addition, foundry losses due to shrinkage and unsound castings are liable to increase.

45. Regardless of the correctness of these speculations, however, it is apparent that the properties of malleable iron are due to the iron matrix; the graphite can tend only to weaken the whole. Further work will have to be done to show the effect of the size and distribution of the graphite on the physical properties.

SOME FACTORS AFFECTING THE RATE OF MALLEABILIZATION

46. Various factors have been pointed out in the introduction to the paper which are known to affect the rate of malleabilization. In the work done at the University of Michigan to date, a

quantitative study has been made on the effects of temperature, silicon content, total carbon content and furnace atmosphere, the results of which are summarized briefly here. It will be attempted to show their effects upon the two fundamental factors set forth previously, namely, on atomic mobility and graphite nucleus formation.

Temperature.

47. The rate at which graphitization of the cementite carbon takes place is affected greatly by the soaking temperature used. For example, first-stage graphitization is more rapid at 1800 degs. Fahr. than if a soaking temperature of 1600 degs. Fahr. is used. The relationship between the time necessary to complete this stage and the temperature is logarithmic,^{3,4} and for an iron of 1.25 per cent silicon, is shown in Fig. 11.

48. This relationship is given for irons of other compositions also for purposes of comparison. The quantitative position of the lines is correct for the irons investigated, which were air-furnace irons made in the same furnace of the same raw materials

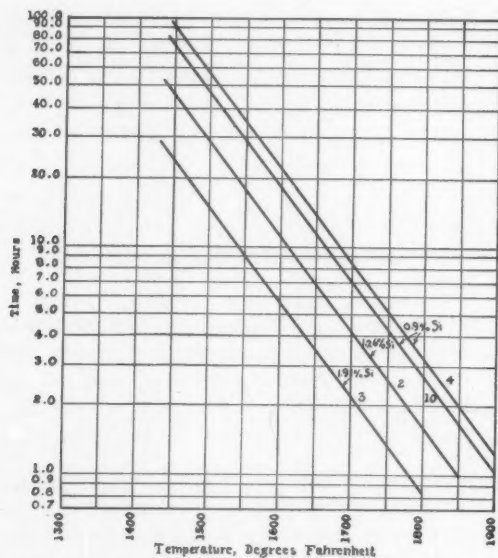


FIG. 11—EFFECT OF TEMPERATURE ON THE TIME NECESSARY TO COMPLETE FIRST-STAGE MALLEABILIZATION.

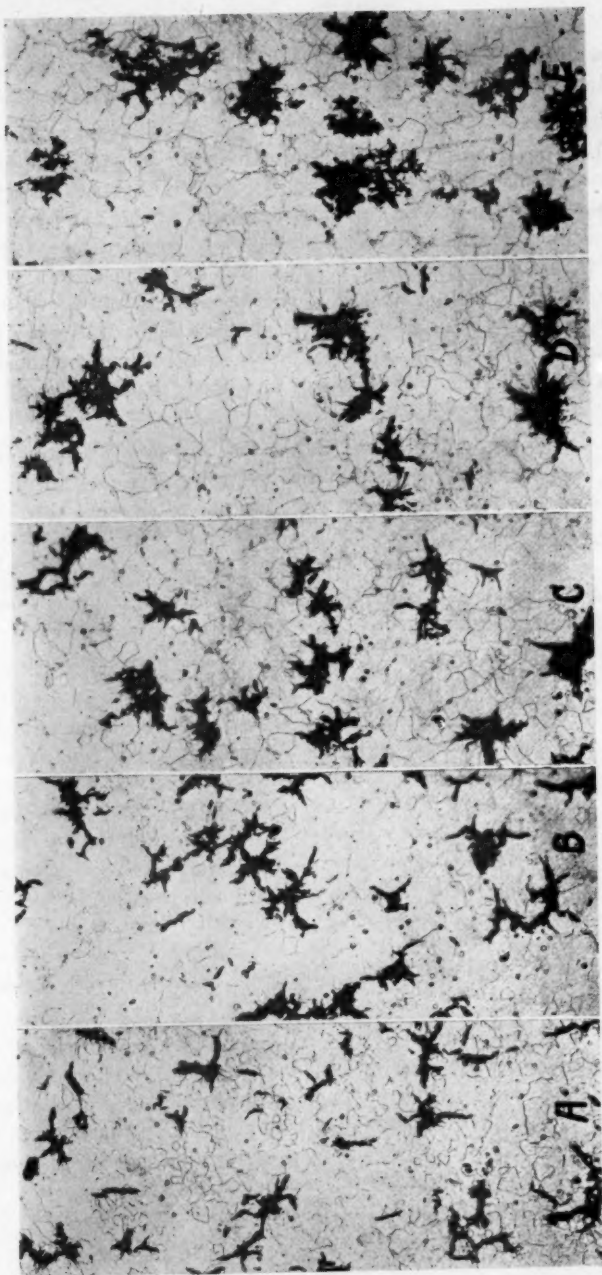


FIG. 12.—IRON MALLEABILIZED WITH VARIOUS SOAKING TEMPERATURES. ALL SPECIMENS ETCHED, X100. A: 1920 DEGS. FAHR. SOAK. B: 1800 DEGS. FAHR. SOAK. C: 1700 DEGS. FAHR. SOAK. D: 1600 DEGS. FAHR. SOAK. E: 1500 DEGS. FAHR. SOAK; SOAKING TIME FOR THIS SPECIMEN WAS INSUFFICIENT BUT FAIR.

and cast in sand molds. Graphitization rates can be modified by changing these conditions; for example, by using metal molds or by the use of other melting processes.

49. The mobility or the diffusion velocity of carbon in iron has been shown by Ishiwara⁵ to be a logarithmic function of the temperature and to follow a curve quite similar to the curve of the relationship between graphitization rate and temperature. It is likely that the effect of temperature upon the malleabilization rate is largely due to its effect upon the mobility of the carbon. This point can be further substantiated mathematically by the fact that the equation for the process of graphitization of malleable iron is quite similar to the usual formulas for diffusion phenomena.

50. The work of Kikuta shows that temperature similarly affects the process of graphitization below the critical range. A few runs made by the present writers seem to support this conclusion.

51. Temperature, however, also has an effect upon the nucleus^{6,7} formation. Iron malleableized with a high initial soaking temperature has, in general, smaller and more numerous graphite particles than the same iron malleableized with a low initial soaking temperature.

52. Figs. 12-A to 12-E, inclusive, show at 100 diameters the structure of specimens of an iron containing 2.43 per cent carbon and 1.26 per cent silicon which were malleableized with initial soaking temperatures of 1920, 1800, 1700, 1600, and 1500 degs. Fahr., respectively. It is apparent that the higher the temperature at which graphitization began—that is, at which the graphite nuclei were formed—the smaller and the more numerous are the resulting graphite particles. They also exhibit less tendency (on high-temperature annealing) to assume the spheroidal form and seem, instead, rather to follow the original austenite grain boundaries.

53. To be sure, the selection of the soaking temperature for practical purposes must be governed also by cost and by consideration of factors such as warpage, scaling and decarburization. With better designed furnaces and with controlled atmospheres, it is likely that the soaking temperatures may be raised to about 1725 degs. Fahr. or over, whereas some plants soak at as low as 1550 degs. Fahr. at present.

Silicon.

54. The silicon content is a most important variable in the making of malleable iron. Silicon raises the critical points, as is shown in Fig. 13. This is significant because it permits a higher temperature for second-stage graphitization, which, from the conclusions set forth above, will materially reduce the malleableizing time.

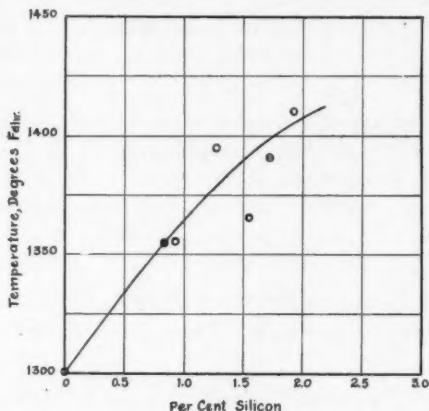
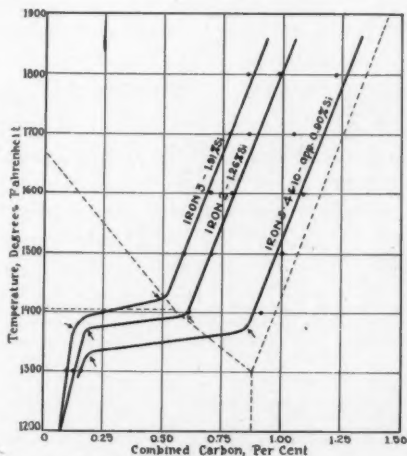
FIG. 13—EFFECT OF SILICON ON THE Ar_1 RANGE.

FIG. 14—EQUILIBRIUM DIAGRAMS.

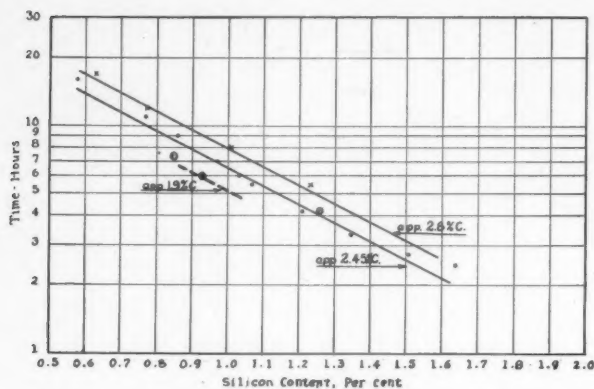


FIG. 15—EFFECT OF SILICON AND CARBON ON TIME TO REACH EQUILIBRIUM AT 1697 DEGS. FAHR. (KIKUTA)

Table 2

ANALYSES OF IRONS

Designation.	Carbon, Per cent.	Silicon, Per cent.
17	2.00	0.72
16	2.06	0.79
5	1.89	0.93
15	2.06	1.04
19	2.06	1.12
18	2.05	1.21
3	1.91	1.92

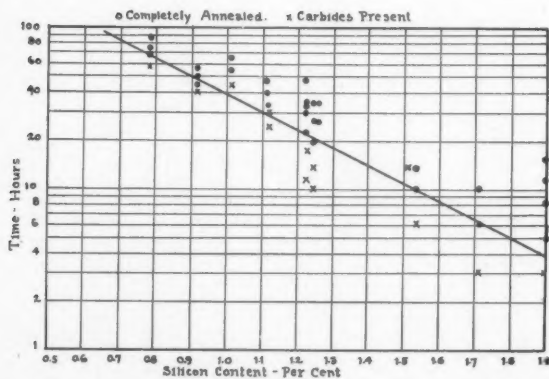


FIG. 16—EFFECT OF SILICON ON SECOND-STAGE ANNEALING.

55. Silicon also reduces the solubility of carbon in austenite. Fig. 14 shows equilibrium diagrams of irons of various silicon contents. This means that with high silicon, more graphitization is accomplished in the first stage, which is comparatively rapid as compared with the second stage.

56. Furthermore, with high silicon, due to the decreased solubility, there will be less carbon left to be graphitized in the second stage. In fact, if a white iron were made with about 4.5 per cent silicon, the solubility of carbon in austenite would be so low that malleable iron could be made in a single first-stage operation.⁸

57. The rate of first-stage malleabilization at 1697 degs. Fahr. for irons of varying silicon content, as obtained by Kikuta, is given in Fig. 15. A few points obtained by the present writers at 1700 degs. Fahr. are inserted which show fair agreement. These results indicate that with increasing silicon, the time for first-stage graphitization decreases logarithmically.

58. Second-stage graphitization was studied in a series of irons of varying silicon contents. The analyses of the irons are given in Table 2.

59. These irons were heated to insure equilibrium at 1700 degs. Fahr., cooled to 1400 degs. Fahr. slowly enough to maintain equilibrium, and were finally held at 1325 degs. Fahr., which is below the A_1 range for all the irons studied. Specimens of each iron were removed from time to time and examined metallographically to observe the progress of malleabilization. Fig. 16 presents graphically the time necessary to complete the process.

60. It is evident that, as in the case of first-stage graphitization, the time necessary to effect second-stage graphitization likewise decreases logarithmically with increasing silicon content. These findings are in accord with those of Kikuta. The cycle used above the critical was insufficient for iron No. 17; hence, the results on that material were rejected.

61. Figs. 17-A to 18-C show at 100 diameters the structures of all the irons except iron No. 17 in the completely malleableized condition.

62. A study of these photomicrographs shows that as the silicon content is increased, the size of the graphite particles decreases and their number in a given area increases. Hence, the



FIG. 17—A: 1.91 PER CENT SILICON. B: 1.26 PER CENT SILICON. C: 1.12 PER CENT SILICON. ALL SPECIMENS ETCHED, X100.

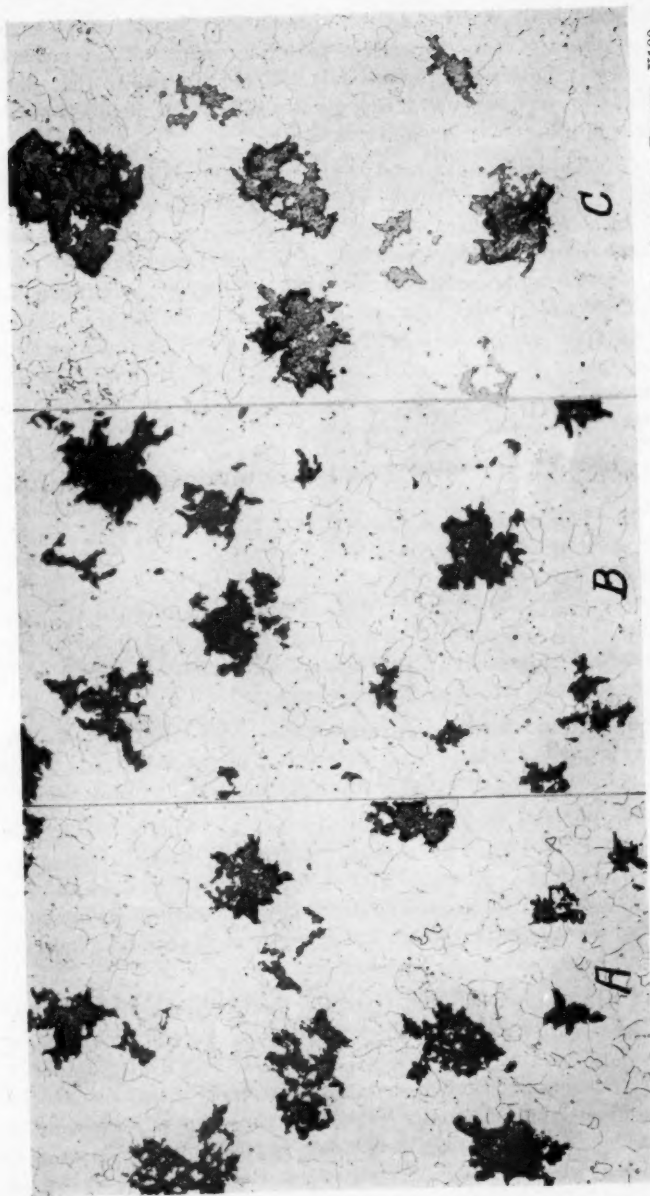


FIG. 18—A: 1.04 PER CENT SILICON. B: 0.91 PER CENT SILICON. C: 0.79 PER CENT SILICON. ALL SPECIMENS ETCHED, X100.

conclusion is drawn that silicon aids nucleus formation. The increased rate of malleabilization with increasing silicon must be due mainly to this effect, since it is difficult to conceive that slight changes in silicon content can greatly affect the mobility of the carbon atoms at any fixed temperature.

63. The silicon content to be used commercially has been governed in the past by melting and casting practice. With 2.5 per cent carbon a silicon content of 1.25 per cent cannot be exceeded without danger of the formation of primary graphite. In addition, consideration has to be taken of the fluidity, melting point, shrinkage and general ease and economy of manufacture. Nevertheless, since greatly improved physical properties and annealing cycles under 20 hours are obtainable, it may prove feasible and economical for certain types of work to adopt low-carbon, high-silicon irons despite their disadvantages.

Carbon.

64. The total carbon content, for all practical purposes, has little effect upon the time necessary for graphitization above the critical. Naturally, a higher content requires more time than a lower one. At 1700 degs. Fahr., in irons containing 0.9 per cent silicon, it will take about 2 hours longer for one containing 2.5 per cent carbon to come to equilibrium than for the one containing 2.0 per cent carbon, other things being equal.

65. Kikuta reported greatly reduced periods for annealing below the critical temperature in irons of high total carbon. This same point was investigated in the present study.

66. Irons of varying carbon contents and with about 0.9 per cent and 1.2 per cent of silicon, respectively, were investigated. Experimental procedure similar to the foregoing was used and the time necessary for graphitization below the critical range was observed metallographically. The analyses and annealing periods to complete second-stage graphitization are given in Table 3.

67. It is apparent that from the limited number of tests, at least, no conclusions can be drawn as to the effect of total carbon on the graphitizing rate below the A_1 . Kikuta believes that a higher total carbon content accelerates graphitization, due to the increased amount of temper carbon present at the inception of second-stage malleabilizing, which acts favorably as nuclei or centers upon which further graphitization takes place. It would

Table 3

ANALYSES OF IRONS

Designation.	Carbon, Per cent.	Silicon, Per cent.	Time in Hrs. at 1325 Degs. Fahr. over 105
12	1.68	0.89	
5	1.83	0.94	37.0
7	2.52	0.90	47.5
M	2.70	0.92	44.0
B	1.75	1.25	17.5
18	2.05	1.21	22.5
2	2.43	1.26	24.0

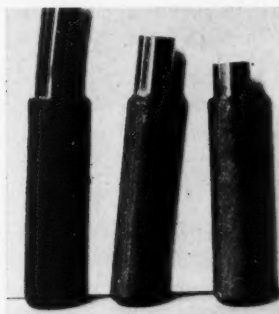


FIG. 19—SURFACE OF IRON ANNEALED IN A GAS ATMOSPHERE.

seem, however, that other factors such as slight differences in the sulphur or phosphorus contents, in the origin of the raw materials, or in the melting and casting practice, exert a greater effect upon the rate of malleabilization than does the total carbon.

Other Elements.

68. Many other elements have been studied^{9, 10, 11, 12} with respect to effect on the rate of graphitization. In general, nickel, aluminum and titanium tend to favor graphitization, while manganese, sulphur, chromium and molybdenum retard graphitization.

Atmosphere.

69. The work done at the University of Michigan showed that the furnace atmosphere had little appreciable direct effect upon the rate of graphitization. Oxidizing, neutral and reducing atmospheres were investigated.

70. The indirect effect upon the speed of graphitization is, on the other hand, of considerable importance. By the maintenance of non-oxidizing atmospheres in the furnace it is possible to eliminate the use of packing material, which procedure will save money in heating and time to attain temperature. The use of packing material entails about 50 hours of heating to bring the charge up to heat and retards the cooling rate to such an extent that short cycles are entirely unattainable.

71. Fig. 19 is an unretouched photograph of some tensile bars which were annealed in a proper gas atmosphere. The narrow portion had been ground before annealing and nothing except wiping in a cloth was done to clean the surface after annealing. Note the freedom from scale.

72. Fig. 20 is a photomicrograph showing the edge of an iron malleableized in a proper gas atmosphere. Note the freedom from pearlite rim and decarburization. Graphite particles extend to the very surface.

ANNEALING CYCLES

73. All this experimental work had as its goal the determination of the characteristics of malleabilization and of the shortest annealing cycles for the production of malleable iron. Malleabili-

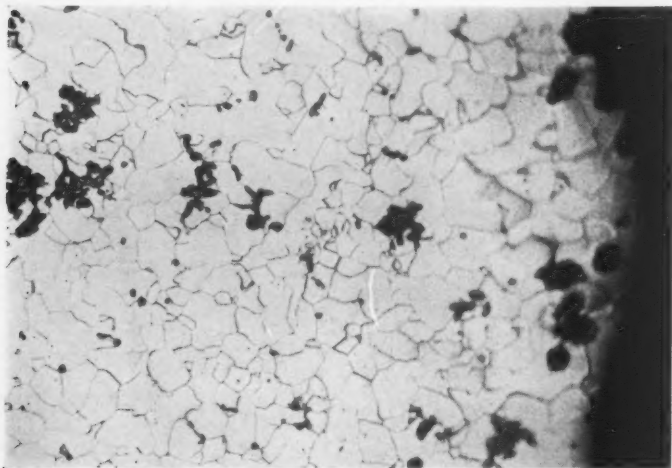


FIG. 20—MICROSTRUCTURE OF IRON ANNEALED IN A GAS ATMOSPHERE. NOTE ABSENCE OF DECARBURIZATION. ETCHED, X150.

Table 4
MINIMUM MALLEABLEIZING CYCLES

Silicon, Per cent.	Time at 1700	Time	Time at 1325	Total
	Degs. Fahr., Hrs.	from 1700 Degs. Fahr., to A ₁ , Hrs.	Degs. Fahr., Hrs.	Time, Hrs.
0.7	20.0	20.0	85	125.0
0.8	16.0	16.0	65	97.0
0.9	12.0	12.0	50	74.0
1.0	10.0	9.5	40	59.5
1.1	8.0	6.5	30	44.5
1.2	6.0	6.0	24	36.0
1.3	5.0	4.5	18	27.5
1.4	4.5	3.5	14	22.0
1.5	3.5	3.0	11	17.5
1.6	3.0	2.0	8.5	13.5
1.7	2.3	1.5	6.5	10.3
1.8	2.0	1.5	5	8.5
1.9	1.6	1.0	4	6.6
2.0	1.4	1.0	3	5.4

zation was found to take place in the following stages:

(a) Decomposition of massive cementite, Fe_3C , at the highest or soaking temperature to form graphite.

(b) Elimination of graphite from saturated austenite as the temperature is dropped to the critical range. If the temperature is dropped too rapidly, pro-eutectoid cementite may be formed instead.

(c) Graphitization of the eutectoid cementite below the critical range.

74. Table 4 gives the shortest annealing cycles for air-furnace irons of varying silicon contents with carbon contents between 2.0 and 2.5 per cent as obtained in this study.

75. These cycles do not take into consideration the time necessary to bring the charge up to heat or the time consumed in cooling so that it can be handled. As the silicon is increased, the critical point likewise is increased; hence, a higher second-stage temperature may be used than 1325 degs. Fahr. This will tend to shorten the annealing time. As has been pointed out before, the annealing characteristics of an iron are modified, aside from changes in composition, by differences in raw material, by the type of melting employed, by the rate of cooling of the white casting, and by general casting conditions.

CONCLUSIONS

76. It would seem, from a study of the results set forth, that the major problem in short-cycle malleableizing must be one of furnace design and atmosphere control. In many of the batch-type furnaces used at the present time, over 50 hours are taken to bring the charge up to heat and up to 20 hours to cool the work after malleabilization is completed. The use of packing material makes the cooling rate from the soaking temperature so slow that time is wasted at this point.

77. If over 70 hours are taken up in non-profitable heating, short-cycles are entirely out of the question. There are commercial plants today which have taken advantage of good furnace design and, with an iron of average composition of about 1.1 per cent silicon content, have cut their production cycle to under 60 hours total time.

78. If still greater reductions in time are to be made, they will have to be effected through the use of higher silicon alloys and by the close control of the raw materials and of the melting and casting practice.

ACKNOWLEDGMENTS

79. This study was sponsored by the Committee on Industrial Gas Research of the American Gas Association. Its progress was greatly aided by the encouragement and counsel of E. D. Milener of that organization. Thanks are due to the Ford Motor Car Co. and to the Malleable Iron Research Institute for the white irons used and to the Advisory Committee on Short-Cycle Malleableizing for their valuable advice and assistance in laying out the program of research.

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¹¹ U. S. Patent, No. 1,640,674, August, 1927.

¹² U. S. Patent, No. 1,636,657, July, 1927.

DISCUSSION

ORAL DISCUSSION

CHAIRMAN R. J. TEETOR:¹ These papers are of utmost importance to the malleable industry. The work being done at the University of Michigan has developed data and conclusions that will lead to others, and Mr. Highriter's review presents material very valuable for study. The control of temperatures and the control of atmospheres undoubtedly will open up possibilities of producing irons of various physical properties, and will lead to extension of products made from a white-iron base.

¹ General Manager, Cadillac Malleable Iron Co., Cadillac, Mich.

W. R. BEAN:² In Mr. Highriter's paper it was brought out that the effect of chilling facilitated graphitization. It was developed in the paper of Messrs. White and Schneidewind that the proximity of the carbon particles affects the strength, which is brought about by a control of the path of rupture in breaking. At least, that is my belief, and this ties in with the question of how much more quickly thin sections can be annealed than heavier sections.

Rule-of-thumb annealers have held (I do not know to what extent they still do) the idea that it took longer for the heat to penetrate and produce its effect on the structure of a heavy-section casting. Some ten years ago we observed that in the ordinary malleable wedge test piece there was a great difference in grain size, as shown by the microscope, between a section taken at the point of the wedge with a thickness of about one-eighth inch, and a section taken near the base with a thickness of approximately one-half inch.

Considering these things together, we have three conditions in the point of the wedge, the thin section: We have a small grain; we have the effect of chilling, of rapid cooling, which facilitates graphitization; and we have the effect of the close proximity of the carbon spots, one to the other. Taking the whole picture, I believe we can say that the difference in rate of graphitization between a thin-section and a heavy-section casting is the result of chilling, which determines the grain size. This, in turn, accounts for the greater difficulty of graphitization of the coarse or heavy section, in which the carbon nuclei are dispersed at greater distance.

As to the difference in time of annealing the thin and the thick section, I do not know whether anyone has made a study which will answer completely the question asked, but fundamentally it is tied up with these considerations.

In connection with the equipment mentioned by Mr. Highriter, and which is a product of our company, in developing that equipment and working out the cycle we have not violated any fundamental principles of regular annealing practice. We do not go to a high temperature with the resultant coarsening of the grain and of the carbon particles. We hold to a normal temperature, and the test results show normal properties in the test bar. We obtain the shorter cycle by dealing with a smaller mass through which it is possible to distribute the heat.

Annealing of malleable iron in a short period of time is a matter of heat distribution, heat absorption and heat dissipation. These are the three main factors in practical annealing of malleable castings. As soon as the load is withdrawn, the oven is reloaded, thereby conserving the heat in the oven structure. The conservation of the heat provides a better ignition condition, permitting the use of less fuel.

It is possible to reach the correct temperature in a shorter time. The smaller mass and the better heat distribution, with more liberal spacing between the pot stacks, provides the condition for dissipation of heat rapidly down to a temperature of 1400 degs. Fahr., followed by

² Vice-President, Whiting Corp., Pulverizing and Combustion Equipment Div., Harvey, Ill.

slow cooling (about 8 degs. Fahr. an hour) from that point down to withdrawal of the load at approximately 1200 degs. Fahr.

We can anneal just as well in 84 hours as in 96, but in the ordinary course of operation an annealing cycle should be a multiple of 24 hours because there are not many malleable foundries whose operating schedules are such that the car can be withdrawn and reloaded in the middle of the night one time, and in the middle of the day on the next run. Thus, we establish four days or 96 hours, unless we can complete it in three days. We know that the cycle can be made in three days, but to do so requires temperatures not altogether practical; some economies would be lost.

It has been demonstrated very definitely that in the pulverized-coal, quick-anneal oven there is less decarburization of the exterior of the castings, which show a black fracture to the surface. While some authorities may not agree with me, I have long contended that the all-important condition determining machinability is controlled by decarburization in annealing. This is of great importance to automotive castings and pipe fittings or other castings which are threaded or whose surfaces are otherwise machined.

D. P. FORBES:³ In relation to the time of heat treating thick-section castings over thin-section castings, we find there is a decided increase in time required, particularly at the higher temperatures, in short annealing heavy-section castings—so much so that on extremely heavy sections it is necessary to run them through the heating cycle twice, provided there are not sufficient quantities to justify a special annealing cycle for the heavy castings. I do not know what the exact relationship would be, but there is a considerable difference in time required.

CHAIRMAN R. J. TEETOR: As I understand it, all the work done at the University of Michigan has been on test bars of the same size. Thus the question, while very important, would not have been examined in the investigation.

R. SCHNEIDEWIND: Kikuta has performed much work on this problem. In 1926 he showed variations of 200 per cent in annealing time in different rates of cooling white iron.

W. H. DOERFNER:⁴ Mr. Highriter has shown by graphs that so-called quick annealing runs from 72 to possibly 100 hours. We have a furnace that will produce 84 tons of annealed iron a day, and we can do it in 59 hours on a commercial basis. From the standpoint of fuel economy, we use just 23 gallons of oil per ton of iron annealed.

We run to the higher-silicon, higher-carbon irons. The iron probably will run 1.05 per cent silicon and probably 2.70 to 2.75 per cent carbon, which gives a standard product.

W. R. BEAN: All our work has been done with the idea of taking any composition that comes in the ordinary routine production of malleable castings, whether 0.70 or 1.0 per cent silicon. Until such time as the

³ President, Gunit Corporation, Rockford, Ill.

⁴ Works Manager, Saginaw Malleable Iron Div., General Motors Corp., Saginaw, Mich.

process and practice are worked out to get exactness in the important elements, it seems important to deal with what can be counted upon regularly in operating the plants as they are at present.

W. H. DOERFNER: At times we have received castings from several air-furnace producers, and we have put this iron through our regular anneal. Apparently the iron annealed all right and the test bars were satisfactory; that was regular 2.40 to 2.50 per cent carbon iron.

J. H. LANSING:⁵ Regarding the iron just mentioned by Mr. Doerfner, with 1.10 per cent silicon and 2.70 to 2.75 per cent carbon, what about the primary graphite?

W. H. DOERFNER: We cast white without any mottles.

R. SCHNEIDEWIND: With regard to Mr. Doerfner's irons I have examined specimens of his irons under the microscope and found very little trace of primary graphite.

CHAIRMAN R. J. TEETOR: It might be interesting to ask Mr. Doerfner for an explanation, since most other producers using the air-furnace process find it impossible to do what he says.

C. F. JOSEPH:⁶ I believe the answer is due to the fact that in our process we use considerable steel. I believe that if this same iron was made with the steel content that we use in the charge, probably the same thing could be accomplished by anyone. The more steel used in the charge, the more carbon there will be in the iron, still without free carbon.

H. W. HIGHBITER: Might not also the degree of superheat involved be a factor?

C. F. JOSEPH: That is correct. The temperature of the molten iron in the air furnace probably would run around 2650 to 2800 degs. Fahr. (I believe it is on the high side, 2800.) We begin pouring at about 2900 degs. Fahr., the temperature to which iron is heated in the electric furnace. If that 2900 temperature is dropped down to 2850 degs. Fahr., the iron will mottle much more readily, of course.

However, I believe the most important factor is that the more steel used in the charge, the less chance there is for primary graphite to form. In fact, in our charge there is no graphitic carbon except what is in the pig iron that goes into the charge. If a pig iron of approximately 2 per cent silicon was charged, considerable graphite also would be charged and there would be a tendency to mottle the iron much more easily.

In our case, however, we charge in the cupola for duplexing around 10 or 12 per cent of iron. This gives a graphite content of around 1.60 per cent, whereas in the ordinary air furnace about 50 per cent pig iron will be charged, which will have a carbon content (mostly in the free form) of some 3.5 per cent or better.

W. R. BEAN: On that theory, should we not get a different material, when using chilled-cast or machine-cast pig, than we formerly had when all of the pig that went into the air furnaces was sand cast? In other

⁵ Works Manager, Danville Malleable Iron Div., Allith-Prouty Co., Danville, Ill.

⁶ Metallurgist, Saginaw Malleable Iron Div., General Motors Corp., Saginaw, Mich.

words, if the amount of graphitic carbon in the charge is a controlling factor on graphitization in solidification, should that not be true?

C. F. JOSEPH: How much less graphitic carbon is there in a piece of iron in a pig iron cast in molding sand, over the machine cast method?

W. R. BEAN: I have no figures as to the amount, but there seems to be considerable difference, judging from the fracture. This question came up very definitely in some studies made about 25 years ago, when we were in the transition stage between sand-cast and machine-cast pig.

C. F. JOSEPH: I do not think there is much difference in the percentage of graphitic carbon. At least, I am positive there is none in our case. The percentage of graphitic carbon will run about the same whether it is machine cast or sand cast.

W. R. BEAN: The percentage of total carbon would run the same, but not the percentage or amount of graphitic carbon.

C. F. JOSEPH: Graphitic carbon is what I mean.

H. W. HIGHRIE: Mr. Joseph is speaking of 12 per cent silicon iron, in which case the high silicon content would cause nearly complete graphitization whether sand cast or machine cast. In a pig iron of 1.75 to 2.25 per cent silicon, undoubtedly there is somewhat of an increase in the amount of combined carbon due to chilled casting.

C. F. JOSEPH: The only free carbon is a little in the pig iron.

W. R. BEAN: I have always been inclined to the belief that the principal difference in graphitization between the electric furnace and the air furnace is the amount or degree of superheat. I may be right or I may be wrong, but it has seemed that may be the case.

W. H. DOERFNER: Partly in answer to this question of pig iron carrying graphite, in the past we have found it necessary at times to use a certain amount of 2.25 or 2.50 per cent silicon iron, due to the fact that we ran short of sprue. When we did that our iron had a tendency to mottle more than when using straight high-silicon pig iron. We merely used the pig iron as a filler.

WRITTEN DISCUSSION

W. R. BEAN: The technical nature of this paper and the fact that it had not been preprinted, prevented a full discussion at the time of presentation. One feature was discussed by the writer, as appears in the record of the oral discussion, and an attempt now will be made to cover some points in more detail.

Small scale or laboratory experiments and studies and the equipment used point the way for production, equipment, methods and processes, but it is seldom possible in the larger masses to accomplish all that is indicated by the laboratory work.

This reference is prompted by the introductory description of equip-

ment used, but particularly by the temperature reference in paragraph 11, indicating maintenance of temperatures within ± 5 degs. Fahr. over long periods. It is believed that in quantity annealing of malleable castings on a production basis, with oven loads of 10 to 15 tons, control within plus or minus 25 degs. Fahr. would represent very good performance with any of the methods of heating that have been employed or may be employed in the industry. We submit this figure as being within practical limitations.

The matter of atmosphere control is important and the studies made throw some new light on this subject. Beyond question, there are possibilities of improvement over conditions which have existed in the past, and the contribution to this subject will be helpful.

Fig. 3, showing the iron-carbon diagram, or a partial diagram applicable to malleable iron containing 1.25 per cent silicon, is a valuable addition to the literature on this subject. This silicon content, however, does not represent a large proportion of the malleable iron produced today, although it does represent approximately the content of malleable castings possessing the highest physical properties when this content is accompanied by a carbon content in the vicinity of 2.10 per cent.

The photomicrographs, Figs. 4-9, inclusive, together with the discussion of these, bring out the different stages of graphitization and the relation of these stages to temperature in a very clear manner. Fig. 8 discloses incomplete malleabilization, which some years ago was attributed to rapid cooling around the critical point and at that time designated as "bulls-eye" structure.*

The authors deserve praise for the most excellent metallographic work which is represented here, and the method of preparation of the samples which leaves the carbon particles intact is especially helpful in studies of the micrographs.

The effect upon physical properties of malleable iron of a higher silicon and lower carbon content is one of the interesting developments of recent years. Further study is justified, bearing in mind always that in castings of heavy section the tendency of high silicon to promote primary graphitization in solidification must not be overlooked. Generalization from study of test bar sections or castings of similar dimension in thickness may lead to incorrect assumptions.

There is also another point not to be lost sight of, namely, the effect of high silicon or the tendency of high silicon to promote inter-crystalline embrittlement under certain conditions† of cooling.

The work of the authors adds new facts to the effect of temperature on the rate of malleabilization or graphitization, and it summarizes the work of some other authors on this very important subject. This adds material of value for investigators and for producers of the product.

It has been demonstrated in actual practice during the past year that in pot-type annealing ovens with castings placed in packing, it is practicable to hold for soaking at temperatures of the order of 1750 degs.

* *Fractures and Microstructures of American Malleable Cast Iron*, W. R. Bean, H. W. Highriter and E. S. Davenport, TRANSACTIONS A. F. A. (1920), vol. 29, p. 321.

† "Deterioration of Malleable in the Hot Dip Galvanizing Process" by W. R. Bean, TRANSACTIONS, American Inst. of Mining and Metallurgical Engrs., 1923.

Fahr., and that temperatures of 1800 degs. Fahr. may be reached in the soaking period and maintained for periods of 5 to 10 hours without apparent injury to the product.

The statement in paragraph 52 to the effect that annealing or soaking at the higher temperature at which graphitization begins, produces smaller and more numerous graphite particles, is contrary to general belief of the past. Micrographs *A* to *E* inclusive, of Fig. 12, corresponding to the temperatures recorded, do show carbon deposits of greatly differing form and dispersal. There do not appear to be tensile test values corresponding to these structures, and annealing temperatures. Further work by the authors which would correlate these values would be most interesting and, beyond question, beneficial to the industry.

Visual study of fractures of castings and test specimens annealed at high and at low temperature shows an apparently coarser structure accompanying the high-temperature anneal, and the general opinion is held that castings annealed at high temperature do not possess as high strength and as great ductility as those annealed at lower temperature. This conclusion may not be justified, and it is sincerely hoped that further study will be pursued by these authors.

The discussion of the effect of silicon content on critical points in malleable iron, as shown in Fig. 13, is most interesting; we, at least, had not realized that the critical point is raised as it apparently is by high silicon. In products where the silicon is consistently high, this fact might be put to valuable practical use in determining the temperature at which withdrawal of castings from the oven could be made safely.

The fact that, in the presence of high silicon, smaller amounts of carbon are left to be graphitized in the second stage, also is of interest and of possible value in relation to the holding time in this period of the annealing cycle.

In paragraph 62 and in the micrographs referred to in paragraph 61, evidence contradictory to past beliefs is submitted. Here we would urge correlation of physical tests with these structures. The question which persists is whether materials corresponding to Fig. 17-A are equal in tensile strength and ductility to materials corresponding to the structure of Fig. 18-C. The appearance of the graphite deposit in Fig. 17-A resembles more that of gray cast iron than of malleable cast iron, raising the question as to the actual effect upon strength and ductility.

Many producers of malleable iron still believe that high carbon aids graphitization in annealing. This idea is not so generally held now as formerly, and the facts recorded will aid in dispelling this incorrect assumption.

The subject of atmosphere is a complex one, tied in with limitations of a practical nature imposed by costs of different fuels in different localities, and further complicated by the fact that investment in existing equipment or the cost of different types of new equipment renders uneconomic the adoption of the ideal, in many instances. If it were practicable to eliminate packing materials without greatly increasing the finishing cost in straightening castings of irregular section and diverse shapes, it then would be practicable to make more extensive use of equipment and fuels which would lend themselves more readily to a more

nearly definite condition of atmosphere within annealing ovens.

The use of packing material, as stated in paragraph 70, does not entail 50 hours of heating to bring the charge up to heat, although packing material does retard both heating and cooling.

Records are available from regular practice on ovens of 10 to 15 tons casting capacity with a total mass of approximately 37 tons in pots, packing and castings, showing temperature of 1600 degs. Fahr. at the center of the lowest temperature pot attained in 16 to 24 hours, with a holding temperature between 1600 and 1700 degs. Fahr. for 20 to 28 hours, and complete anneal in 84 hours. These results are obtained without regard to chemical analysis, simply taking the regular run of heats with silicon contents varying between 0.80 and 1.0 per cent.

With this cycle the oven load is withdrawn when the castings in the pots are approximately 1200 degs. Fahr., and 84 hours therefore represents the complete cycle of the anneal.

It will be seen that we do not agree with all of the conclusions of the authors, but we do consider their contribution to the subject of malleabilization or graphitization of white cast iron to be most valuable. The sponsors of this study deserve the highest gratitude of the entire malleable industry and of users of their product.

In Reply

R. SCHNEIDEWIND: In the fifth paragraph of Mr. Bean's written discussion he points out that our Fig. 3 is not applicable to most malleable irons. On the other hand, our Fig. 14 contains not only the diagram of Fig. 3 but also diagrams of other irons, one of which is the most common commercial malleable iron.

Foundry Factors Affecting Steel Casting Design*

By K. V. WHEELER,† LEBANON, PA.

Abstract

The foundry has, at best, only partial control over several factors in the production of steel castings. Most important of these factors is design. The author points out some basic reasons why cost and quality are unavoidably affected by design. Manufacturing peculiarities of molten steel are discussed, relating to shrinkage of the steel as the liquid metal cools. Attention is called to the need for considering location of the parting line of the pattern, straight lines being preferable. Cores should be kept to a minimum. Effects of shrinkage and volume contraction are discussed in detail. It is most important to have the sections so designed that no small sections are located between heavy sections and the risers to cut off the flow of hot metal from the risers. Examples are given showing the effect of the various factors affecting design.

INTRODUCTION

1. It is universally recognized that many of the problems involved in making castings are controllable by the foundry. Some such problems are partially dependent on the availability of suitable raw materials. Extensive research, conducted energetically since the World war, has advanced the effective use of these materials. However, there are several factors in the production of castings over which the foundry has, at most, only partial control, with the result that responsibility for their influence on the final results is divided between the maker and the user.

2. Design is the most important factor for which the foundryman generally can assume little responsibility. The purpose of this paper is to point out some of the basic reasons why cost

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and quality are unavoidably affected by design. It is hoped that the conditions explained herein will give the engineer a better understanding of the founding problems which require solution before the most economical application can follow constructional design.

3. Founders of steel, iron and nonferrous metals have many problems in common, but the special technique necessary in each division of the casting industry varies with the natural peculiarities of the metal during manufacture. With the exception of the light alloys of aluminum and magnesium, the steel foundry is the latest comer in the field, and as steel castings usually have been a direct substitution for weaker materials, very little thought was given previously by the designer to the manufacturing behavior of this metal, which differs quite radically from that of iron and nonferrous alloys, and is greatly influenced by design.

4. A review of the innumerable casting problems presented to the steel foundryman during the past twenty-five or thirty years makes it quite plain that steel casting design has been a direct legacy from the older iron and nonferrous products of the foundry. When stronger casting parts were required, the change in metal from iron to steel was accepted as being the correct procedure. Comparatively little thought was given to the different action of the new material during manufacture, except to provide additional finish or lagging to maintain required dimensions (due to the greater degree of contraction of the steel), or to increasing sections in certain members so as to offset the lower degree of fluidity of the steel, for filling all mold cavities.

MANUFACTURING PECULIARITIES OF MOLTEN STEEL

5. Preliminary to discussing specific details of design, it might be well to point out some of the manufacturing peculiarities of molten steel which make it differ from other casting materials. The principal differences are higher melting and pouring temperatures, greater eroding influence on the mold material, and greater shrinkage and contraction.

6. The higher pouring temperature (approximately 2900 degs. Fahr. for many kinds of castings) and the more severe erosion of the mold, necessitate more refractory mold materials than those employed for iron and nonferrous alloys. These characteristics also influence the method of "gating," a foundry term com-

prehensively indicating the size and location of one or more channels through which the molten steel is introduced into the mold cavity.

7. The greater shrinkage and contraction of cast steel through the cooling range, from pouring temperature to room temperature of the solidified casting, presents by far the most difficult problem. Because of it, complications in non-uniform metal sections of castings which can be readily made in other metals often present insuperable problems to the steel foundryman.

DESIGN

8. Design, as commonly understood in the foundry, has been defined as (a) the general outline or shape called for by the mechanical requirements; (b) the thickness of the prevailing section, particularly in relation to the total surface area of the part, and (c) variations in sectional thicknesses from part to part, to meet the needs of the completed job of which the casting represents one unit.

9. Design of steel castings and its influence on the cost and quality of the finished product is not a new subject. It has been discussed to considerable extent, particularly in the last few years. Possibly the author's contribution presents nothing novel or unique.

10. Nevertheless, it is his conviction (shared by many steel foundrymen) that the scope of useful steel casting application has been seriously restricted, due to engineers' unfamiliarity with the manufacturing peculiarities of the metal and with the influence of design on the cost of the finished casting. No reasonable opportunity should be neglected to place this information, of great commercial importance, in the hands of designers.

Causes of Faulty Design.

11. One of the causes of faulty design of steel castings lies in the fact that no one ever has established, and probably never will establish, many definite limitations of the foundry art in producing sound castings of intricate shape. A further difficulty is due to the fact that clever foundrymen occasionally produce sound castings of most complicated design, thereby setting up

precedents in which commercial considerations are sacrificed to pride of craftsmanship.

12. Every manufacturing process has its limitations. Why should foundrymen attempt to camouflage theirs and, without protest, continue to take work which they know beforehand is doomed to failure when gaged commercially?

13. This problem is not merely a question of fillet size, of finish allowance, of round versus square corners, of relative thickness of joining sections. Its consideration embraces the countless combinations of casting members merged into one integral piece, their relation to each other and to the whole, the behavior through the cooling range of the metal from which they are made, and last but not least, the cost and utility of the finished part.

14. Obviously this problem is much too complex to permit of hard and fast rules covering all contingencies. Close cooperation between the designing engineer and the foundry engineer is the only solution. However, there are several well-recognized basic principles, some of which this paper will attempt to describe.

15. The author has discussed this subject on numerous occasions and with many designing engineers, and with their cooperation he has changed many a casting from a high-cost, impractical combination of bosses, ribs, feet, flanges, etc., to a more simple design of casting which the foundry could make at a lower cost, with assurance that the resulting part would meet every requirement.

The Problem of Molten Steel Behavior.

16. In the course of these conversations, many engineers of the highest type have exhibited an extremely hazy knowledge of the behavior of molten steel. Some of them believed the limitations of the steel foundry art were established solely by the ability to introduce the molten steel into the mold cavity so that all members of the casting apparently were filled out. If the sections were of sufficient thickness to permit this, no further consideration was given to the design.

17. The real problem of the steel foundryman lies in the behavior of the steel after it is in the mold, and not in the process of putting it into the mold.

Two Phases of the Design Question.

18. A general discussion of this subject should be divided into two phases, both having definite influence on the quality and cost of the finished casting. The first phase is the mechanical consideration of design, dealing with certain shop operations that, to some extent, are common to iron and nonferrous foundries. The second phase may be termed the metallurgical consideration of design; it deals with its effect on what was previously called the manufacturing peculiarities of the metal.

19. Mechanical considerations cover the cost and type of pattern equipment, the relative production of good castings per molding man-hour, the elimination of unnecessary cores, and the susceptibility of the rough castings to distortion and to the production of excess metal such as risers, fins, etc., which influence the amount of work necessary in the finishing department and detract from the general appearance of the product.

20. Metallurgical considerations cover the influence of section on the final state of the solidified metal in the casting itself. This involves a consideration of the contraction in volume which occurs while the steel is cooling from the molten to solid condition, the further contraction of the casting members after solidification, and the influence of design on localized stresses, affected by heat treatment.

MECHANICAL CONSIDERATIONS OF DESIGN

Patterns.

21. In this paper the author will not attempt to designate what constitutes a most suitable pattern, as this varies with the practice in individual foundries. As a general statement he would emphasize the fact that a proper cost balance can and should be maintained between the pattern shop and other departments.

22. These departments are so interrelated that the consideration of any specific job must weigh each in relation to the others. To illustrate, a cheaply constructed pattern may increase the molding, core or cleaning department work out of all proportion to the saving in the pattern shop; and, conversely, expensive pattern equipment may not be justified in the savings it will effect in the cost of the finished castings. These factors must be balanced. Bearing in mind the number of castings required on the

present order and the potential demand for such castings in the future, a safe rule to follow is: "The greater the number of castings required, the more justifiable is the initial pattern expense, providing such expense is intelligently incurred to reduce the cost of other foundry operations."

No Absolute Rules for Mounting Patterns.

23. Hard and fast rules cannot be laid down as to when patterns should or should not be mounted, or as to the selection of the material from which the pattern should be made. Each instance is a case unto itself and should be handled with the co-operation of the foundry producing the castings. Failure to appreciate this often has cost the consumer much unnecessary expense in the making of patterns, sometimes unsuitable for foundry practice, and occasionally of an elaborate, costly construction quite out of proportion to the number of castings required.

24. Design in itself, however, may affect the cost of pattern equipment apart from other foundry considerations. The least expensive types of pattern construction are those which employ to the greatest practicable extent the use of machine tools common to pattern shop equipment, such as lathe, planer, jointer, sander, etc. Conversely, the most expensive pattern equipment is that which necessitates the greatest amount of hand work. These statements are relative and are based on the premise that other factors are equal.

Straight Parting Lines

25. Casting design which permits the pattern maker to establish a straight parting line on the pattern—i.e., a line from which all other surfaces of the pattern will draw from the sand of the mold without the use of cores or loose pieces—is the most desirable from the standpoint of pattern cost. This type of pattern construction, in foundry language, is called "flat back." A pattern made thus can be placed flat on the molding board in one-half of the mold and can readily be drawn from the sand after the sand is compressed around the pattern.

Split Pattern.

26. Another example of this type is the so-called "split pattern," which is composed of two pieces separated on a straight

parting line, one piece of which is rammed in each part of the mold and is easily drawn from the sand. In making this type of pattern equipment the pattern maker establishes the parting line on the uncompleted pattern and then trues this parting line on the jointer or sander. This is a rapid operation and results in a perfectly flat surface. From this parting line it is a relatively simple task to establish the correct amount of draft or taper on all pattern surfaces.

27. Fig. 1 shows a typical pattern of the split type. An added advantage in patterns of the straight parting-line type is

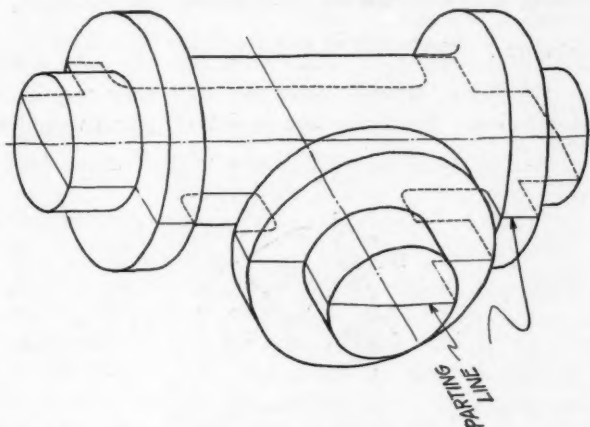


FIG. 1—EXAMPLE OF SPLIT PATTERN, SHOWING FLAT PARTING LINE THROUGH CENTER OF PATTERN, MAKING FOR EASE OF MOLDING BY HAND OR FOR MOUNTING ON FLAT PATTERN MOUNTING BOARDS FOR MACHINE MOLDING.

their adaptability to mounting for machine molding. They require only straight, smooth, pattern-mounting boards on which they are secured in position, to register accurately with each other in the completed mold.

Irregular Parting Lines

28. When the design is of such nature that a straight parting-line cannot be established on the pattern, the pattern maker must resort to one or more of the following alternatives: (a) loose pieces, (b) external cores, or (c) an irregular parting line.

Loose Pieces.

29. When loose pieces are used they must be secured to the main pattern in some manner (as by dowel pins or dove-tail) so that they will remain in the mold when the main pattern is drawn from the sand and subsequently may be removed by hand. A simple illustration is shown in Fig. 2. The round boss on the vertical pattern wall, apparently for reinforcement around the hole subsequently drilled through this boss, is placed below the parting line of the pattern. In many cases such bosses can be run to the parting line as shown, without affecting the utility of the casting. This modification simplifies pattern construction and subsequently increases molding production.

External Cores.

30. (b) When external cores are used they require core-box construction. From the standpoint of pattern equipment

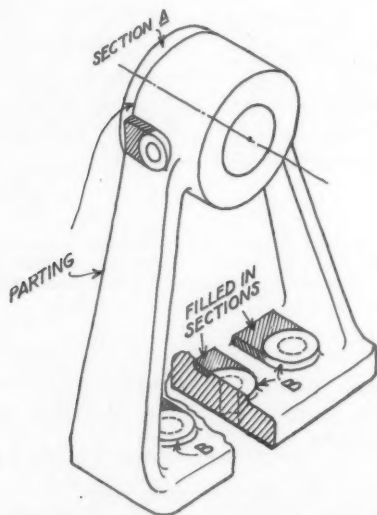


FIG. 2—PATTERN WITH BOSSES (B, B) ON SIDE. IF LEFT AS ROUND, BOSSES WILL HAVE TO BE LEFT AS LOOSE PIECES, ENTAILING ADDITIONAL MOLDING COST. IF SECTIONS BETWEEN BOSSES AND TOP OF PATTERN ARE FILLED IN, THE BOSS SECTION CAN BE SOLID WITH THE PATTERN, MAKING FOR EASE IN MOLDING. SECTION A, IF SPLIT FROM MAIN PATTERN, PERMITS HAVING A FLAT PARTING LINE.

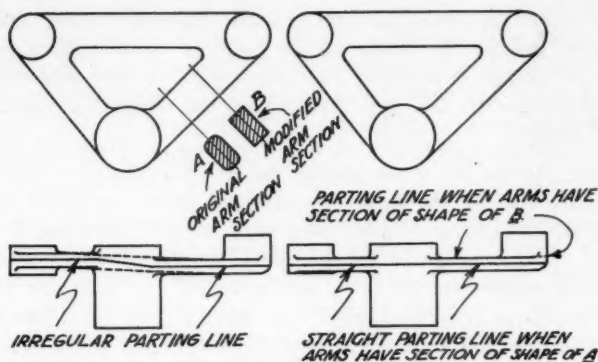


FIG. 3—DIAGRAM OF PATTERN SHOWN IN PHOTOGRAPH OF FIG. 4. LEFT, ORIGINAL DESIGN WITH IRREGULAR PARTING LINE; RIGHT, REDESIGN TO PERMIT STRAIGHT PARTING LINE.

cost, coreboxes almost invariably are more expensive than patterns per square inch of casting area produced.

Tapering Patterns.

31. (c) Designs requiring irregular parting-line patterns necessitate a determination of this parting on the pattern and the tapering of all surfaces from it, so that the pattern can be drawn from the sand if the mold is parted on that line. Establishing this line on the pattern and working the desired taper from it practically calls entirely for hand work and materially increases the pattern cost.

32. A small rocker arm, illustrated in Figs. 3 and 4, shows a simple type of pattern requiring an irregular parting line. The

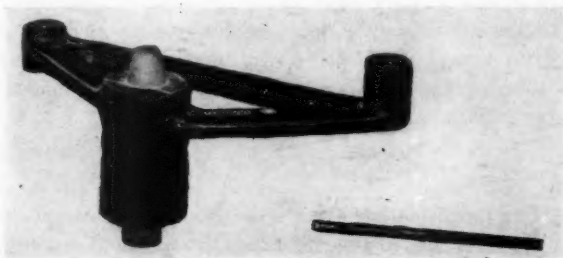


FIG. 4—SAME PATTERN AS FIG. 3, AS ORIGINALLY RECEIVED WITH IRREGULAR PARTING LINE.

arms extending from the hub are on different planes, and the member joining the bosses at the ends of these arms is on an inclined plane. Excepting the lower part of the hub and the circular bosses at the ends of the arm, the pattern is practically hand made.

33. If the two arms joining the hub are placed on the same plane as that of the member connected with the bosses at the ends, the pattern could have been split on the centerline of these arms. A further simplification would be the elimination of the rounded corners on the three arm members (as shown at *A* and *B*, Fig. 3), as they then would be made in one piece instead of split, and the hand work to round the corners would be obviated. That part of the hub and bosses above the arms could be split from the main pattern on one plane. This design probably would reduce the pattern cost 50 per cent.

34. If a pattern of this type is used for making appreciable numbers of castings, it should be mounted for machine molding. The increase in the cost of mounting patterns with irregular parting lines, such as the one illustrated, is even greater than the higher cost of the pattern itself, as special mounting boards must be fashioned to suit the irregular parting line, necessitating hand work to match both sides of the board. Such boards have no value as mounting boards for any other patterns, and if the design is changed to destroy the present parting line, the chances are that the boards as well as the patterns will be scrapped.

35. The examples mentioned, showing the effect of design on pattern construction and on cost, are extremely simple. The principles involved, however, are applicable to all patterns, regardless of their complexity. Changes to design suggested by this phase of foundry work may alter preconceived notions of contour, and at times may require corresponding changes in other units of the assembly. If these factors are considered while plans are on the drawing board, many economies can be made without interference with other parts of the assemblage.

Molding and Core Making

36. In addition to their effect on the pattern cost, the factors discussed above also influence the production per molding man-hour, and consequently the cost of molding. The simplest and most economical design from the molding standpoint is one

of the "flat back" type (already mentioned) and which has no loose pieces, cores, or deep pockets. Obviously, designers must depart from such simplicity in the creation of parts to meet mechanical requirements. However, the nearer the approach is made to the ideal design from the standpoint of molding cost and production per molding man-hour, the lower becomes the cost of the finished castings.

37. Quality as well as cost is affected by these factors. Through long use, the contacting surfaces between loose pieces and main pattern become worn, permitting inaccurate placement. Dimensional allowance must be made for the size of the core as compared with the size of the mold, so that the former can be placed in the latter without crushing the sand.

38. A core may be placed slightly out of position, causing mis-matched members in the casting. An irregular parting line, especially on loose patterns, requires much molding skill and experience to shape the mold parting properly. Slight errors of judgment in doing this work may cause heavy fins of metal which must be removed in the cleaning room or may result in crushed molds and dirty castings.

39. Purely from the standpoint of cost, cores as ordinarily required are objectionable in any foundry. To the steel casting maker they present a special problem, as they usually are harder and more unyielding than the sand of the mold, and for this reason frequently set up undesirable resistance to casting contraction, occasionally resulting in shrinkage cracks.

40. When internal cores are unavoidable, the design should provide a sufficient opening through the casting for the necessary support of the core, and for permitting the rapid escape of gases generated in the core when the hot metal comes in contact with it. Chaplets are used to supplement coreprints for core support, and in certain classes of work they are quite satisfactory. However, on pressure work they are highly undesirable, as their complete fusion to the casting is never assured, and leaks through the casting walls may result where chaplets are located.

Finishing Department

41. The simple design of casting that is without cores and has uniform cross-sections goes through the finishing department

with least work and expense. Irregular contours requiring cores invariably produce more fins, etc., which must be removed. Non-uniform metal sections usually require more risers which must be removed in the finishing department.

42. Deep pockets and cored recesses require slower and more careful blasting (an expensive operation) to remove the adhering molding and core sand and the annealing scale. Designs requiring risers above curved or irregular surfaces obviously are more difficult to clean to pattern line than are those having flat surfaces. Many times this factor alone may double the entire cleaning cost.

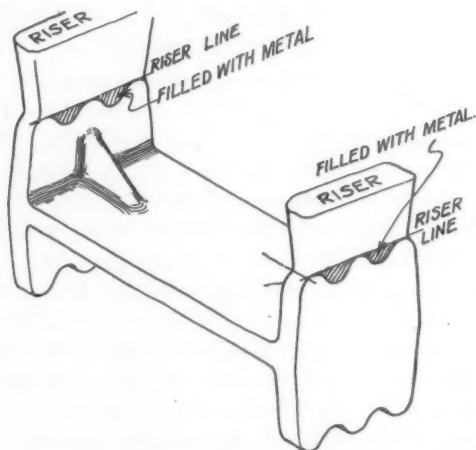


FIG. 5—CASTING ILLUSTRATING HOW CURVED SURFACES REQUIRING RISERS MAY BE REDESIGNED TO GIVE SMOOTH SURFACES WHICH PERMIT ECONOMIES IN REMOVING RISERS.

43. The average foundryman's desire to reproduce accurately the pattern contour in the finished casting, frequently could be assisted by changing the shape of certain surface areas from irregular to flat, with no bad effect on the usefulness of the part and frequently with good effect on the appearance of the casting. (See Fig. 5.)

METALLURGICAL CONSIDERATIONS

44. The phase of this paper dealing with metallurgical considerations in casting design is not intended to be a discussion of

the finer points of metallurgy, such as those phenomena detectable only in the laboratory by means of analysis and microscopical examination. It is intended to cover the more practical aspect of this subject, as that aspect is reflected by normal inspection methods.

45. Refinements in steel making and in methods for the production of cast steel parts after they are poured, are assisting the steel foundryman to keep pace with the progressive developments in the manufacture of other industrial materials. However, before the point is reached where the difference between good and bad steel castings may be satisfactorily measured by metallurgical yardsticks to the greatest attainable extent, much can be accomplished in the every-day practical operation of the



FIG. 6—BLOCK CASTING SECTIONED TO SHOW EXTENT OF INTERIOR SHRINKAGE WHEN NO RISERS ARE EMPLOYED TO PROVIDE FEEDING METAL. SHRINKAGE TAKES PLACE WHILE METAL IS FLUID.

foundry, and in the development and application of a technique to handle problems constantly presented in the shape of irregular groupings of bosses, ribs, flanges, etc. Some designs properly may be called metallurgical deformities, from which sound castings free from injurious defects are desired but cannot be economically produced.

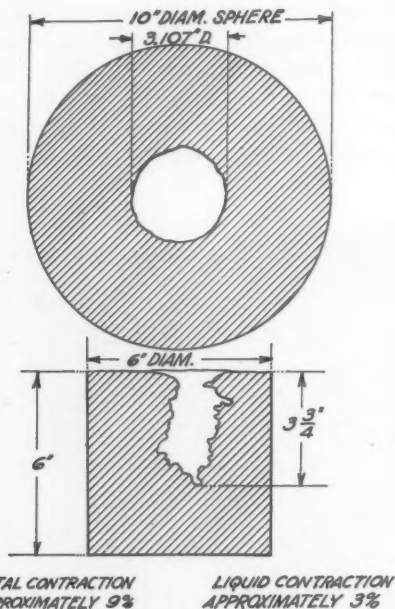


FIG. 7—DIAGRAMS SHOWING APPROXIMATE EXTENT OF SHRINKAGE CAVITIES FORMED WHEN NO RISERS ARE EMPLOYED FOR FEEDING.

Shrinkage and Volume Contraction

46. Ordinarily carbon steel, which is used for the bulk of steel castings, has a volume contraction from normal pouring temperatures to the solid state at room temperature, of approximately 9 per cent. A part of this contraction, approximately 3 per cent, takes place while the metal is liquid, as illustrated in Fig. 6. The balance of this contraction occurs after solidification and is reflected in the shrinkage allowance in making patterns.

47. The natural result of this shrinkage peculiarity in the finished product is influenced tremendously by casting size, shape and mass. All new designs are new problems, some being quite simple, others extremely complex. The steel founder must anticipate the behavior of the metal through the solidifying and cooling stages in all members of every casting.

Contraction During Solidification

48. Considering first the contraction of the steel during solidification, let us assume a casting of spherical shape without any attached members that would modify, locally, the rate of cooling. Assume that the mold for this casting is filled instantaneously with molten steel. Cooling would start at the surface and progress toward the center, the liquid interior would supply the necessary metal to compensate for the shrinkage around it, and the result would be a solid shell with a shrinkage cavity theoretically in the center, as illustrated in Fig. 7.

Purpose of the Riser.

49. To prevent this condition in castings, provision must be made to supply the needed liquid steel to compensate for this contraction in the casting. This is accomplished by the use of risers or reservoirs of metal placed directly over the casting members, the metal from which gravitates into the casting before solidification is completed. The final shrinkage thus is transferred from casting to riser, the latter, of course, being removed.

50. Proper functioning of the riser cannot be assured unless a correct temperature differential in the casting can be controlled so that the riser itself is the last point to solidify. This may be accomplished by mass or by a method of introducing the metal into the mold, or by a combination of the two.

51. The ideal method of introducing this metal, from the standpoint of correct solidification progress alone, is to pour the mold from the top through the riser. By this method the riser receives the last metal, has the greatest cooling lag, and consequently can supply the needed metal to casting members below it. The erosive action of the molten steel and the limitations of available mold materials make this method impractical in many cases, and necessitates mass to counteract the adverse temperature differential due to method of pouring.

The Best Designed Casting.

52. To prevent isolated "hot spots" in the casting, the casting should be so designed that this shrinkage can move progressively from all members to the riser. From this standpoint the best designed casting is the one in which all members progressively increase in thickness to one central location where a riser can be placed. The steel ingot is an ideal example, tapering from the bottom upward.

53. If mechanical demands will not permit this gradual and progressive tapering of all sections to a common point, it is necessary for the foundryman to provide additional reservoirs of reserve metal to supply those sections which are cut off from the central riser. While this is a practical solution for the control of solidification shrinkage of the several casting members in themselves, it often presents the additional problem of restricting the free contraction of the casting after solidification, thereby setting up cooling strains or cracks.

54. To counteract these solid shrinkage stresses, relief



FIG. 8—CASTING HAVING MANY ISOLATED HEAVY SECTIONS, NECESSITATING A NUMBER OF RISERS TO PROVIDE FEEDING METAL FOR ALL HEAVY SECTIONS SHOWN.

measures are employed to permit the free contraction of the casting after solidification, by the use of crushable molding material, necessarily limited, or by removing the sand around the riser as quickly as possible after pouring. Occasionally such preventives are insufficient. Instances occur where it is desirable to arrange for one centrally located feeding riser.

Multiple Risers.

55. Fig. 8 illustrates a casting with many isolated heavy sections, necessitating a number of risers to take care of the shrinkage in all members. It is not difficult to picture the additional resistance to contraction set up by these reservoirs of steel. The increase in cost of this waste steel, sometimes representing as high as 50 per cent of the melt, and the further expense of removing this metal from the casting and dressing down the surface to the required contour, merits consideration from the standpoint of economy.

Heavy Sections Joined by Light Sections.

56. The most difficult problem confronting the steel foundryman is the design that has relatively heavy sections joined together by light members, the thicker ones being so located that risers cannot be placed over each one individually. Other things being equal, mass regulates the rate of solidification. Consequently, the lighter sections solidifying first, cut off the feeding action from the risers with the resulting effect of shrinkage cavities in the heavier sections.

57. Fig. 9 illustrates this solidification phenomenon as affected by sections. A plain wedge 10 in. long and 5 in. wide, tapered from 1 in. to 3 in., cast with the large end up (*B*, Fig. 9), was sectionalized to show the shrinkage cavity in the riser and perfectly sound metal in the casting. The same figure shows this wedge cast with the small end up (*A*, Fig. 9), also sectionalized, disclosing a somewhat smaller cavity in the riser with solid metal directly underneath through the lighter part of the wedge, and a shrinkage cavity in the heavier section of the wedge which could not draw the required metal from the riser, due to premature solidification of the thinner section above it.

58. The figure also shows a sectionalized casting $2 \times 2 \times 10$ in., with riser (*C*, Fig. 9). For most practical purposes this cast-

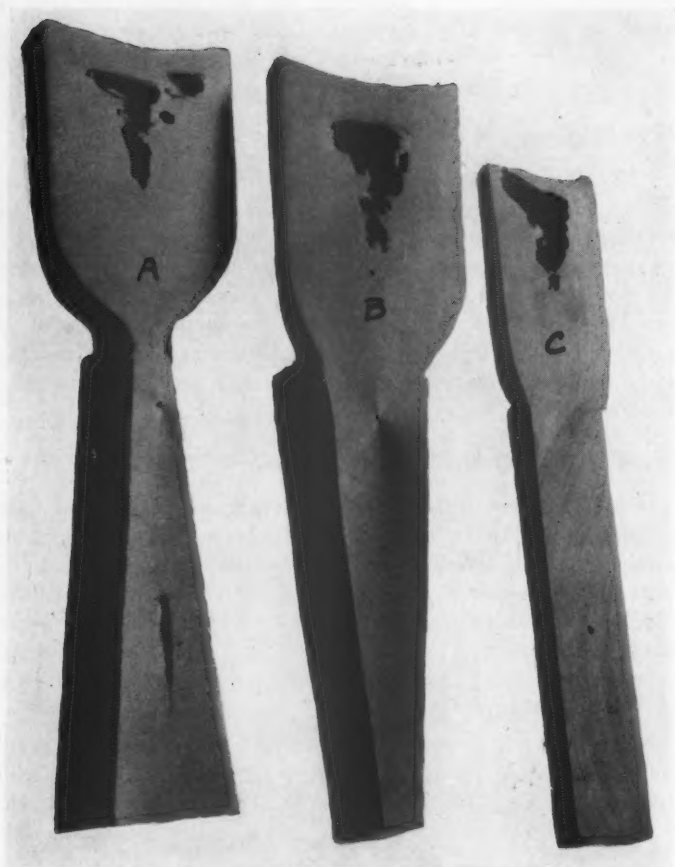


FIG. 9—SOLIDIFICATION PHENOMENON AS AFFECTED BY SECTIONS. A: PLAIN WEDGE 10 IN. LONG, 5 IN. WIDE, TAPERED FROM 1 IN. TO 3 IN., CAST WITH SMALL END UP. SOME SHRINKAGE OCCURS IN INTERIOR BECAUSE SMALL END OF CASTING FREEZES FIRST SO THAT RISER IS SEPARATED BY SOLID METAL BEFORE HEAVY END OF CASTING IS SOLID. B: SAME WEDGE, CAST LARGE END UP, PERMITTING ADEQUATE FEEDING FROM RISER. C: SECTIONED CASTING $2 \times 2 \times 10$ INCHES, WITH RISER. WHILE PRACTICALLY SOLID, THERE IS A SLIGHT UNSOUNDNESS CORRESPONDING TO AN INGOT PIPE.

ing is solid, although there is a slight unsoundness in the center, corresponding to an ingot pipe. This condition is influenced by cross-section in relation to depth.

Riser Applications.

59. Keeping in mind the conditions just described, let us consider the usual type of blank gear (Fig. 10) with which most engineers and machinists are familiar. The most common failing in cast-steel blank gears is a shrinkage cavity at the base of the tooth, midway between the faces of the rim, in line with the center-bead on the inside of the rim.

60. By drawing the largest possible circle (*LC*, Fig. 10) in

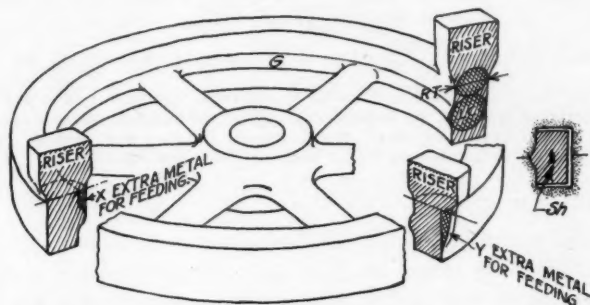


FIG. 10—METHOD FOR SECURING SOUNDNESS IN GEAR BLANK RIM.

a section of the rim of the unmachined casting, it will be noted that the shrinkage (*Sh*, Fig. 10) uncovered in the cutting of the teeth usually corresponds to the center of that circle. The diameter of this circle is larger than the thickness (*RT*, Fig. 10) of the rim above the center, which ordinarily must serve as a feeding channel from the riser to the heavier section. Premature solidification of this part (*RT*) cuts off the feeding action to the heavier section underneath, with the resulting cavity.

61. To overcome this difficulty in cast-steel blank gears, many foundries supply additional metal on the outside or inside of the rim, as shown on the sketch (at *X* and *Y*, Fig. 10), to provide an undisturbed flow of the metal from the riser to the heavier part of the rim until its liquid shrinkage is completely compensated. This supplementary metal usually is removed, increasing the cost

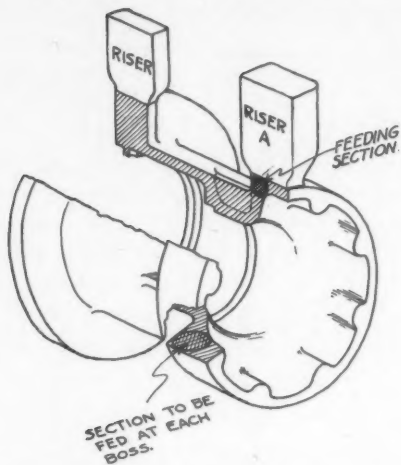


FIG. 11—ORIGINAL DESIGN OF CASTING WHICH DOES NOT PERMIT OF ADEQUATE FEEDING FROM RISERS. SECTION IMMEDIATELY UNDER RISER A, BEING SMALLER THAN SOME INTERIOR SECTIONS, WOULD FREEZE AND CUT OFF FEEDING FROM THE RISER BEFORE HEAVY INTERIOR SECTIONS ARE SOLID.

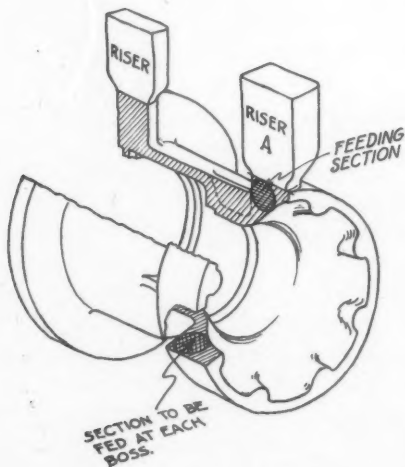


FIG. 12—REDESIGN OF CASTING OF FIG. 11, SHOWING ENLARGED SECTION IMMEDIATELY BENEATH RISER A.

of the castings. If the bead were omitted and the rim tapered, undisturbed feeding from the risers would follow.

62. Another practical application of this principle is a design common to parts that are subsequently joined by numerous bolts or studs around the flange. Fig. 11 illustrates a pressure casting, in one end of which are placed numerous internal bosses for required reinforcement around bolt holes.

63. Obviously, it is impossible to place a riser over each one of these bosses, without which there is not the desired assurance that all will be solid. If a shrinkage cavity appears in any boss, it may divert the drill from its proper direction. If such bosses are subsequently tapped, the cavity will cause much annoyance if not completely removed in the drilling operation. Many times such cavities cause leakage through the bolt holes.

64. The design shown in Fig. 11 was changed as illustrated in Fig. 12, by increasing the metal section between the bosses to provide a feeding channel to all from one riser placed over the flange.

The Use of Chills.

65. When steel casting designs include relatively heavy sections in inaccessible places where risers cannot function, the steel founder must resort to other means to maintain the correct temperature differential in the cooling casting. This usually is accomplished by the use of chills, external or internal.

66. An external chill is a piece of metal shaped to the contour of the casting against which it is placed, which locally accelerates the cooling and solidification of the part of the casting affected. Excepting where chills with flat surfaces can be used, generally they are cast and require the added expense of patterns. An internal chill, usually a piece of rolled metal of a composition similar to that of the casting to be poured, is placed in a relatively heavy section of the mold so that the liquid steel completely surrounds it and in doing so accelerates the cooling and solidification of the metal at that point.

67. The use of either type of chill requires experience and judgment in the selection of size and location, to insure proper functioning. If internal chills are too large they do not become satisfactorily fused to the casting proper; if too small, they do

not balance the cooling rate of the non-uniform metal sections. If external chills are too small they do not balance the cooling; if too large, they are apt to cause small surface cracks where they are placed.

68. Chills must be thoroughly clean to prevent undesirable chemical reaction with the molten steel. If molds containing chills are not poured reasonably soon after closing, the chills are apt to condense moisture and become rusty. When this occurs the liquid steel will not lie quietly against the chills, and gas pockets may be formed in the casting.

Contraction After Solidification

69. To this point the discussion has covered only the effect of mass differential on potential defects in the heavier sections due to an insufficient supply of molten steel to compensate for the shrinkage of solidification, and not appreciably influenced by solid contraction. We will now consider the effect of solid contraction as related to potential defects in the finished part.

70. These defects (either hot tears or shrinkage cracks) usually are manifested at points where metal sections change in mass or direction. They result from a combination of resistance to solid contraction and temporary local weakness caused by temperature differential. Size and shape of the casting introduce a decided influence, as they largely control the severity of the contraction stresses produced.

71. Materials from which molds are made must possess the necessary characteristics to resist the forces of erosion, penetration, pressure, and fusion of the extremely hot liquid steel. These qualities usually militate against compressibility, causing disintegration of the mold material after pouring, which is essential to promote free contraction of the casting through the cooling range.

72. Unrestricted solid contraction of cast steel is roughly $\frac{1}{4}$ in. per lineal foot. As there are practical limits to the compressibility of commercial mold materials, the stresses from contraction are somewhat proportional to the over-all length of casting members. Projections at right angles to the axis of contraction offer serious impediment and should be avoided or minimized as much as possible, especially on long or rangy castings. Many designs will not permit this simplification, and in such cases the

variation in metal section should be extremely gradual, so as to reduce the hazard of local cooling-lag stresses.

Improving Design of Tee Fittings.

73. An ordinary tee fitting is shown in Fig. 13. Dimensions used are arbitrary and for illustration only, as no attempt was made to maintain standard fitting dimensions. Unrestricted contraction of the body would reduce the distance $\frac{1}{2}$ in. between the end flanges. The mold material between the flanges offers very considerable resistance to contraction, thereby setting up rather severe stresses in the casting. These stresses are highly concentrated at the base of the flange, which is also a point of relative weakness, due to change in cross-section.

74. The $2\frac{1}{2}$ -in. flanges, cooling more slowly than the $\frac{3}{4}$ -in. body metal, retard the cooling of the body section immediately

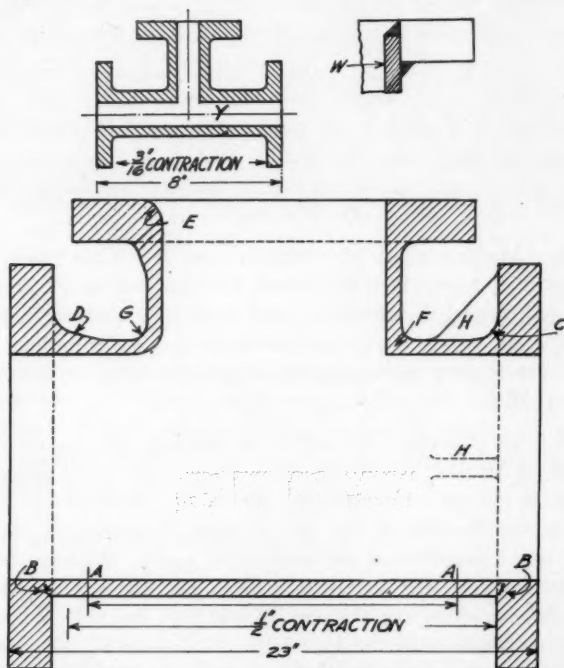


FIG. 13—FACTORS AFFECTING SHRINKAGE AND CONTRACTION OF AN ORDINARY TEE-FITTING.

adjacent. The angular mold formation at this point throttles heat radiation, especially if flange and body have sharp right-angle connection.

75. For illustration, the $\frac{3}{4}$ -in. body section from *A* to *A* (Fig. 13) precedes the $\frac{3}{4}$ -in. section at *B* through the solidifying and cooling stages. Solid contraction seriously commences its work in the *A-A* section, while *B* is still plastic and relatively weak. Unless mold resistance is reduced proportionally to the strength of the metal section at *B*, a rupture or crack will develop.

76. Obviously, the sharp corners *B-B* at the bottom of the sketch accentuate the conditions just mentioned. A fillet (as shown at *C*) on upper section of right-hand flange will facilitate radiation, reduce stress concentration, and increase the local strength of the casting. A further improvement can be made by tapering the body section as shown at *D*, in the upper section of the left hand flange, which graduates the temperature differential between the uneven metal thicknesses of flange and body.

77. Still further improvement is possible by using a generous radius shown at *E*, which also will assist the feeding riser to counteract the shrinkage of solidification. This modification is not without precedent. The sketch (*W*) in the upper right-hand corner is typical of much fabricated construction, employing this detail of design, apparently for reasons of economy.

78. Another point of weakness common to tee-fitting design is illustrated where tee and lateral sections join at *F*. Increased mass and retarded radiation may weaken the metal here at a critical time. This design can be improved by rounding the inside of the casting concentrically with the outside, as sketched opposite at *G*.

79. To illustrate the effect of casting size on contraction stresses, a smaller tee-fitting (*Y*), measuring 8 in. between the flanges, is shown. Unrestricted contraction reduces the distance between the flanges on the cold casting approximately $\frac{3}{16}$ in. under that dimension of the pattern or mold. Whereas the mold material between the flanges of the larger casting must be compressed $\frac{1}{2}$ in., this requirement is less than one-half that amount on the smaller casting; and with the limitations of compressibility in mold materials, the stresses set up in the smaller casting are relatively weaker.

80. Occasionally the most critical surface inspection fails to disclose possible casting weaknesses in the locations similar to those described, even though the contraction stresses actually have produced unsoundness. In pressure castings this unsoundness may be manifested later by leakage when the castings are put under test pressure. It is extremely important, therefore, that castings of the kinds mentioned be designed with these considerations in mind.

Triangular Brackets.

81. A common expedient used by all steel foundrymen to strengthen sections susceptible to concentrated contraction stresses such as those illustrated, is shown at *H-H* in Fig. 13. Triangular



FIG. 14—LEVER CASTING, AN EXAMPLE OF EFFECT OF TEMPERATURE DIFFERENTIAL IN A COOLING CASTING, DUE TO UNIFORM METAL SECTIONS.

brackets of relatively light metal section joining the flange and the body, are spaced around the casting. These brackets, solidifying early, have much greater strength than the more plastic metal in the sections affected by a cooling lag during this critical period. The removal of these brackets from the rough casting is an expensive cleaning operation, and the result detracts from the general appearance of the finished product.

Cooling Lag and Non-Uniform Sections.

82. Fig. 14, showing a lever casting, presents another example of the effect of temperature differential in the cooling casting, due to non-uniform metal section. The heavy metal near the center of the casting cools more slowly than the lighter members and therefore is in a plastic state when the lighter sections com-

mence solid contraction. The riser necessary to take care of liquid contraction in this heavier part accentuates the cooling lag. Resistance of the mold material to the required risers at the ends of the casting, produces stresses sufficient to tear the casting apart through the heavy section at the center, due to its weak plastic condition. This condition can be improved only by making the members of the casting more nearly uniform. (See also Fig. 15.)

Box-Shaped Castings.

83. Another example of this phenomenon is illustrated in Fig. 16, which shows sectional views of box-shaped castings 8 in. square, with different corner designs. With type *A*, concentric inside and outside radii hold the metal around the corners of uniform thickness with the side walls. With this design there is

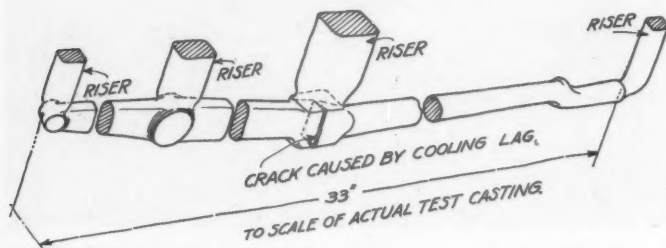


FIG. 15—DIAGRAM OF CASTING SHOWN IN FIG. 14.

no appreciable cooling lag at the corners, providing the radii are large enough in relation to the metal thickness. Hard and fast rules cannot be laid down because the proper size of radius depends to some extent on the size of the box, although it usually is safe to use an inside radius no smaller than the thickness of the wall section.

84. Type *B* shows a square outside corner with an inside radius equal to the corresponding radius in *A*. The heavier section created by this design lags appreciably in cooling, and the result may be a shrinkage cavity in the heart of the corner section, or a shrinkage crack from the inside fillet as indicated. The severity of these hazards also depends to some extent on the relation of wall thickness to over-all size of casting.

85. Type *C* shows sharp corners on the outside and inside surfaces. While the metal section is very nearly uniform, the sharp angle retards radiation and, unless provisions are made to counteract the slower cooling, shrinkage cracks invariably result. The extent of these cracks again depends to some extent on the relation of the metal thickness to the size of the casting. Obviously, design *A* is most desirable from a metallurgical standpoint.

Chills.

86. Chills, usually external, frequently are employed to syn-

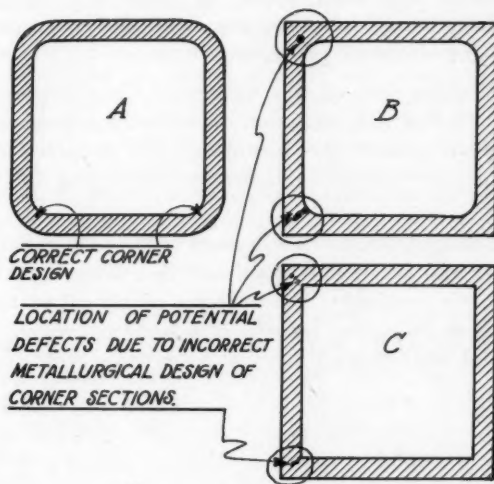


FIG. 16—EXAMPLES OF DESIGN OF CORNER SECTIONS.

chronize the cooling rate in all members of the casting which embodies bad features of design as illustrated in Figs. 13, 14 and 15. Experience and judgment are necessary in selecting the correct size of chill to maintain this balance.

87. The steel foundryman's ingenuity often is taxed to the limit in counteracting the effect of bad metallurgical design. Errors in judgment may result in defective material, usually detected at the foundry but sometimes proceeding through the machining stage, in either case causing delays and adding to the cost of the finished casting.

CONCLUSION

88. Part of the answer to the problem of casting design rests with the steel foundries themselves. They must recognize the practical limits of the steel founding art and maintain a firmer position when confronted by metallurgical deformities impossible to produce satisfactorily in commercial practice.

89. Makers of competitive materials, such as forgings and fabricated parts, are regularly granted concessions in design quite out of proportion to those given the manufacturers of steel castings. The steel casting should not be burdened with unessential trimmings and, thus handicapped, be required to compete with other products where every member is carefully considered from the standpoint of cost of production.

90. Another part of this answer to the problem discussed rests with the designing engineer. He should welcome all useful information regarding the manufacturing peculiarities of the materials he specifies and the factors influencing their cost of manufacture.

91. The final solution lies in much closer cooperation between the designer and the foundryman, and in a better understanding of each other's problems. More careful consideration by all concerned, of these important features of design, will widen the useful scope of steel casting application, to everyone's profit.

High-Test Iron for Pressure Castings

By H. H. JUDSON,* SENECA FALLS, N. Y.

Abstract

Some six years ago a series of experiments was conducted to develop a high-strength iron suitable for use in the fluid ends of high-pressure pumps. These castings have wall thicknesses averaging $2\frac{1}{4}$ in. and weigh 2000 to 3000 lbs. each. Experimental heats proved that the percentage of total carbon present and its condition in the iron were equally important. The lower the total carbon and graphitic carbon, within certain ranges, the stronger and finer grained was the iron. The problem resolved into one of reducing total carbon and of controlling it. Best results were obtained by melting the steel in one cupola and the soft iron in another, mixing to the right proportions in the ladle. This method gave iron with bursting pressures of 6000 lbs. per sq. in. (compared with 3500 lbs. per sq. in. for the original mixtures), machinable and requiring no feeding risers. Control of blast has been found essential. Separately cast test bars are not used, but test specimens are cut from sections of test castings instead.

1. So many articles and papers have been presented during the past two or three years on the subject of high-test iron that another paper might seem superfluous. However, the method used in the author's foundry for the production of high-strength iron is very different from methods hitherto described. Our experiences with this particular iron also are different.

2. It is hoped, therefore, that this paper will present data of interest on these two points, thereby promoting discussion likely to answer several questions still remaining in the author's mind.

Development of Iron for High-Pressure Work

3. Six years ago a series of experiments was conducted in our foundry to develop a high-strength iron that would be suitable for use in the fluid ends of high-pressure pumps, especially the ends of oil-line pumps. These fluid ends or cylinders are

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NOTE: This paper was presented and discussed before one of the gray iron sessions at the 1932 convention of the American Foundrymen's Association.

heavy castings weighing from 2000 to 3000 lbs. each. Wall thickness varies from $1\frac{1}{2}$ in. to $2\frac{1}{2}$ in., the average thickness being $2\frac{1}{4}$ in.; internal sections are much heavier. This gives a slow-cooling casting, which, under our old methods, was prone to develop internal shrinks or draws.

4. The principal purpose of these experiments was to determine what effect the various common elements occurring in cast iron had upon the strength of the castings. The series included heats made up of different burdens, all of which contained steel rails but with various amounts of malleable pig, charcoal pig, low-silicon pig, and alloys of nickel and chromium.

5. Cylinders were cast from these heats and then were machined and tested to destruction. The average bursting pressure was in the neighborhood of 3500 lbs. per sq. in. Tensile tests performed on samples cut from the walls of these cylinders showed a tensile strength of from 30,000 to 35,000 lbs. per sq. in. Chemical analyses showed a range of silicon contents from 0.8 to 2.00 per cent, manganese from 0.5 to 1.00 per cent, and total carbon from 3.10 to 3.40 per cent.

6. The physical test results were not sufficient to meet the needs of the Engineering Department. However, an analysis of the results of the various tests showed that the one element having the greatest effect on the desired properties was carbon. Both the percentage of total carbon present and the condition in which it existed in the casting were found to be of equal importance.

7. Results from the alloy heats were not uniform, owing to the lack of knowledge, at that time, of the proper use of these alloys and the interpretation of the data obtained.

Reduction of Carbon Content

8. The fact that carbon is so important an element, insofar as strength and pressure tightness are concerned, was not new. Experimental heats proved conclusively that it had, above all other elements, the most profound effect on these properties. The lower the total carbon and graphitic carbon, within certain ranges, the stronger and finer grained was the resulting iron. Hence, the problem resolved itself into one of reducing the total carbon content and controlling it.

9. In the cupola, the one simple means of reducing the total

carbon of a cast iron mixture is by the use of steel rails in the burden. Steel rails always had been used in the regular so-called semi-steel mixtures, and their use was continued.

One Cupola for Hard Iron, Another for Soft Iron

10. Since it was so desirable to reduce and also to control the carbon content, and since the use of steel rails in the burden was a means to that end, it was decided to melt the rails in a separate cupola. This would produce a very hard iron, unsuitable for casting. The softening materials then would be melted in another cupola and the two irons mixed in one ladle.

11. An experimental heat was run according to this method, and such excellent results were obtained that the idea was developed until it was practicable in production.

12. Test bars from these early heats were not of much value. The cooling rate of the separately cast test bars was so much faster than that of the cylinders that, although bars and cylinders were of the same chemical composition, the mechanical properties of the iron in the test bars were widely different from those of the iron in the cylinders.

13. To have a more accurate and direct check on each heat an extra cylinder was cast, machined and tested to destruction under hydrostatic pressure. This test proved to be very costly, so a test cylinder was designed of the same wall thickness and general proportions as the pump cylinder but with necessary machining reduced to a minimum. One of these cylinders was cast with each heat and broken under pressure during the remainder of the series.

14. The cylinders from an ordinary semi-steel heat, cast during the original investigation, would develop a bursting strength up to 3500 lbs. per sq. in. The same type of cylinder cast with two-cupola iron would develop a bursting pressure of 6000 lbs. per sq. in. Fig. 1 shows a typical break, on a bursting test, of a line-pump cylinder cast with two-cupola iron. Wall thickness of this cylinder is $2\frac{1}{4}$ in.

Method Used at Present

15. The method finally evolved is as follows: The steel rails, with some spiegeleisen and high-silicon pig, are melted in a

cupola lined to 54-in. diameter. One row of tuyeres, set from 7 to 8 inches above the sand bottom, is used. The tap is continuous and the spout is of the skimming type. The coke bed extends 34 in. above the top of the tuyeres, and the charges used are as follows:

Steel rails	1300 to 1500 lbs.
15% Silicon pig.....	120 to 140 lbs.
20% Speigeleisen	65 to 80 lbs.
Coke splits	180 lbs.

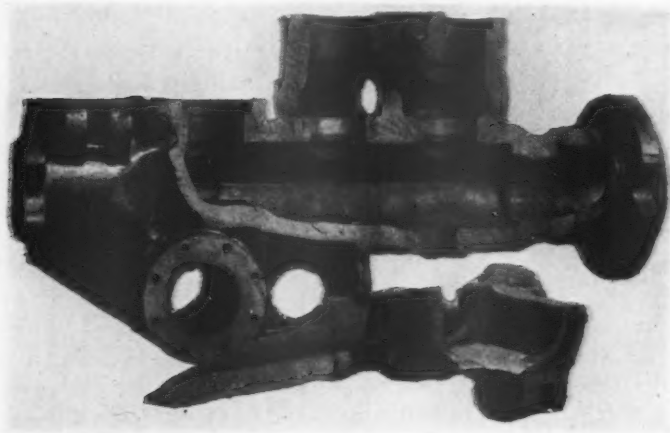


FIG. 1—TYPICAL BREAK, ON BURSTING PRESSURE TEST, OF LINE-PUMP CYLINDER CAST WITH TWO-CUPOLA IRON.

16. Blast is supplied by a motor-driven, positive displacement blower, and the blast is measured by a volume-recording blast meter of the orifice-plate type. The blast volume runs between 5400 and 5600 cu. ft. per minute with a pressure starting at 14 ounces and dropping gradually to 6 or 8 ounces at the end of the heat. The blast volume is held between the stated limits throughout the heat by means of manual control of the blower motor.

17. The 54-in. bed is burned through very completely, a rule adhered to religiously. Then the steel rails, with the speigeleisen and high-silicon pig, are charged carefully by hand. Each charge is kept as level as possible.

Table 1

ANALYSES OF HARD-IRON SAMPLES

(Samples taken from spout at 5-minute intervals
during short heat, all tapped into one ladle.)

Sample No.	Si	S	Mn	P	TC
1	1.07	0.128	0.53	0.080	2.62
2	2.06	0.090	1.44	0.078	2.50
3	2.22	0.082	1.78	0.042	2.40
4	0.91	0.096	0.85	0.067	2.70
5	0.33	0.085	0.97	0.082	2.73

Table 2

PHYSICAL PROPERTIES OF IRON MIXTURE PRODUCED BY
TWO-CUPOLA METHOD

Tensile strength, lbs. per sq. in.....	46,500
Shear strength, lbs. per sq. in.....	51,500
Brinell hardness	212
Bursting pressure, lbs. per sq. in.....	6,000

Transverse Tests (on standard 1¼-in. round arbitration
bars on 12-in. centers):

Transverse strength, lbs.....	5,000
Transverse deflection, in.....	0.09

Table 3

RANGE OF MIXTURES USED

Cupola Charges:

Steel rails, lbs.....	1300 to 1500
Silicon pig, lbs.....	120 to 140
Speigeleisen, lbs.	65 to 80

Soft Iron:

Silicon, per cent	2.40 to 2.70
Sulphur, per cent.....	0.085
Manganese, per cent.....	0.50 to 0.70
Phosphorus, per cent.....	0.45
Total carbon, per cent.....	3.40 to 3.60

Weights:

7000 to 8000 lbs. hard iron.
1800 to 2300 lbs. soft iron.

Resultant Mixtures:

Silicon, per cent.....	1.40 to 1.80
Sulphur, per cent.....	0.10 to 0.11
Manganese, per cent.....	0.85 to 1.10
Phosphorus, per cent	0.150
Total carbon, per cent.....	2.40 to 2.80

Hard and Soft Iron Mixed in One Ladle

18. The cupola stands, fully charged, for an hour and a quarter with the tuyere covers opened wide so as to provide a strong natural draft. The blast is started and the time noted when iron drips past the tuyeres, which usually is 5 to 6 minutes after blast-on. Tap-out comes 6 minutes after these drops are first seen, and an optical pyrometer indicates an apparent temperature of 2550 degs. Fahr. with no correction for emissivity. All the metal is tapped into one ladle.

19. In the meantime, the cupola melting the soft iron has been in blast. A ladle suspended from a crane scale is placed under the spout and a pre-determined weight of soft iron is run into it. It then is poured into the ladle of hard iron from the 54-in. cupola. When sufficient iron has been caught to make the desired mixture, the molds are poured.

20. Table 1 gives the analyses of hard-iron samples taken from the spout at 5-minute intervals during a short heat, all of which was tapped into one ladle, this fact offsetting the wide variation in analyses.

21. Seventy-five hundred pounds of the hard iron of Table 1 were mixed with 2000 lbs. of soft iron having this analysis: Silicon 2.40 per cent; sulphur 0.085; manganese 0.55; phosphorus 0.45; total carbon 3.50. The analysis of the resultant mixture, which was poured into a line-pump cylinder, from which the sample was taken, was as follows: Silicon 1.70 per cent; sulphur 0.105; manganese 1.09; phosphorus 0.152; total carbon 2.74; graphitic carbon 1.99; combined carbon 0.75.

22. The sample was taken through the 2¼-in. wall of the cylinder, this cylinder having 5¾-in. bore and weighing 2300 lbs. It will be readily seen that a casting of this size would cool very slowly. Physical data obtained from this casting are shown in Table 2.

23. Mixtures given in paragraph 21 are for one specific job. The figures of Table 3 show the range of mixtures used.

24. Photomicrographs of Figs. 2 and 3 show that the iron is distinctly of pearlitic structure, with no free ferrite and only occasionally free cementite. The graphite exists in short flakes and is nicely broken up. A fracture through a heavy piece shows a remarkably uniform grain structure throughout.

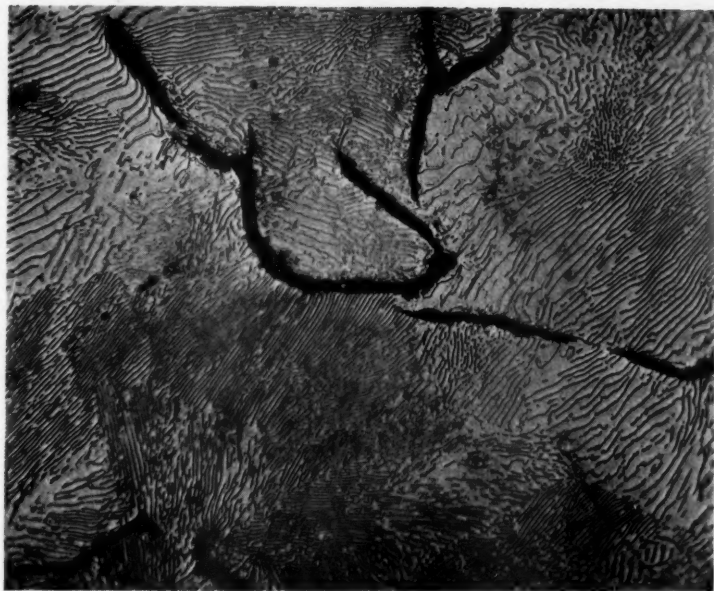


FIG. 2—PHOTOMICROGRAPH OF SPECIMEN TAKEN FROM WALL OF A LINE-PUMP CYLINDER SIMILAR TO THAT OF FIG. 1. ETCHED WITH 5% NITRIC ACID IN ALCOHOL, X500. ANALYSIS: SI 1.47 PER CENT; S 0.097; MN 0.80; P 0.21; TC 2.47.

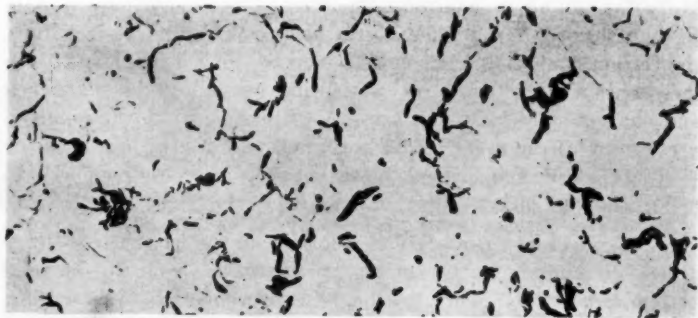


FIG. 3—UNETCHED SPECIMEN, SAME AS IRON OF FIG. 2. X50.

Success with "Two-Cupola" Iron

25. This iron has fulfilled all of our requirements. Over 1000 cylinders of various kinds cast from this metal are in service, operating at pressures of from 450 to 1500 lbs. per sq. in. It is over five years since the first one was placed in service, and as yet we have had no breakage reported from the field.

26. Each cylinder is checked (before it goes to the machine shop) for chemical analysis, shear strength and graphite distribution, all of which are determined from a sample cut from the wall of the casting itself.¹ These three checks enable us to discard any cylinder which may be off owing to poor foundry practice. We can detect faulty cupola practice instantly by means of these tests.

Advantages of Two-Cupola Melting

27. Behind this method of producing high-test iron is the idea that melting the steel in one cupola and tapping all of it into one ladle enables us to gage the carbon content of our final mixture. There is nothing in the steel burden to throw us off, because the burden materials never change, nor does the cupola operation. Soft iron analysis is held uniformly close to specifications from day to day, and more important still is the fact that the quantity used is weighed out accurately. Thus, its effect on the final analysis is known beforehand.

The Coke Bed

28. The coke bed may seem low, but a series of experimental heats was run off to determine the effect of bed height on the iron. Results showed that with uniform blast, coke splits and charges, the carbon content increased with increase in bed height. It also increased with increases in coke splits, providing the blast, bed and charges were held uniform. A 34-inch bed is low enough to prevent too great a carbon pick-up, and coupled with a 1 $\frac{1}{4}$ -hour soaking period and proper blast volume, it is high enough to bring the iron down white hot from the start.

29. The amount of coke through which the molten iron drops is held to a minimum by setting the tuyeres as close to the sand bottom as possible. This, too, helps to prevent carbon absorption.

¹ See "Shear Tests for Cast Iron," A. S. T. M. vol. 31, pt. 2, 1931.

Controlling the Blast Volume

30. The continuous tap works the same way. The iron is withdrawn from the cupola as fast as it melts, so that it does not lie in contact with the incandescent coke in the well of the cupola. Blast volume is held constant so that a uniform melting condition exists; a high blast makes for a lower carbon content, but this gain is more than offset by excessive loss in silicon and manganese.

31. At the start of this development, the blast volume was determined by the speed of the blower, with no means of measuring it exactly nor of holding it uniform throughout a heat. As the heat progressed the pressure drop through the cupola gradually decreased; the blower picked up speed, thus causing a gradual increase of blast. The blast would be approximately 5200 cu. ft. per minute at the start and would increase to 5800 or 5900 cu. ft. at the end. Carbon content decreased slowly through the heat.

32. Castings poured from these heats would show spongy spots under the risers. These defects resembled a combination shrink and gas cavity. Larger and higher risers were used, but still the spongy spots occurred. The molds were made in dry sand and the cores were open and well vented, so that the defects were chargeable directly to the iron.

33. Installation of the recording blast-volume meter brought with it a sure means of measuring and controlling the blast. As soon as the meter indicates an increase in blast volume, the motor is slowed down to the speed that will bring the volume back where it belongs.

Blast Control Eliminates Defects

34. Since inaugurating this practice there has not been the first sign of a defect under a riser. The defect, we believe, was caused by the presence of gas in the iron which was released when the iron set and gathered at the last place to freeze, directly under the riser. This absorption of gas by the iron was caused by a non-uniform melting condition.

35. Toward the end of the heat the increased blast volume brought about an oxidizing condition, or a condition that would introduce gas into the metal. The logical conclusion seemed to be that the increase in blast would tend to raise the melting zone; but, acting to the contrary, it would burn away coke in charges above the melting zone so that the actual bed height was decreased in-

stead of raised. Thus, the melting took place too close to the tuyeres.

36. Control of the blast volume has done away with this condition. There are no gas pockets anywhere in the castings now. Evidently the melting conditions were wrong and now are about correct. In the early stages of development trouble also occurred in getting iron hot enough and fluid enough to pour; at times iron would freeze on the lip of the crane ladle while pouring. Iron of this same analysis, melted with the blast held uniform, now is sufficiently hot and fluid to meet all our needs.

37. The above experiences are mentioned because many foundrymen object to a low-carbon iron as setting too quickly and shrinking excessively. Our experience was quite similar until the melting conditions were corrected.

No Feeding Risers Used

38. Present practice is to cast all jobs of new design in molds without feeding risers. All new designs of cylinders are molded with flow-off risers only, not large enough to feed. Regardless of the sections of the castings, varying from 1½ in. up to 4 in., no risers are used.

39. Castings have been broken up into small pieces and have shown no signs of internal shrinkage, open-grained metal nor gas pockets. One particular job weighing 2500 lbs. has a 1½-in. thick circular pipe section abutting on a section varying from 3 in. to 4½ in. thick and forming a sharp re-entrant angle, a condition which promotes shrinkage. No risers are used in pouring this casting, yet the castings are entirely sound and solid and are tested at 3500 lbs. per sq. in. pressure and do not sweat. They operate under 900 lbs. per sq. in. oil pressure, and even then show no signs of sweating.

40. This same kind of iron is poured into small green-sand jobs, such as pump plungers, glands and levers. Standard gates are used. The iron is very hot, so that we experience no difficulty in getting these castings to run. No risers are used.

Life of the Iron

41. The iron seems to have almost as long a molten life as our other grades, although such was not the case before we hit

upon the proper blast condition. Before, we had difficulty at times in pouring a 5-ton ladle of iron into three molds, without iron freezing on the lip; now, we can hold the metal for 15 minutes before pouring and run into no difficulty with dull metal.

42. This is offered as proof that a low-carbon cast iron does not necessarily have a short molten life. We do not make it a practice to hold the metal in the ladle, because a finer grained structure is obtained by pouring hot.

What Makes Iron Non-Shrinking?

43. The question we would like to have answered is this: What is there about this iron that makes it "non-shrinking," i.e., insofar as shrinkage troubles in the foundry are concerned? Low-carbon cast irons are supposed to shrink excessively, a thought that we, like many others, had entertained. However, this particular iron does not act in that way and we have no explanation to offer as to why it does not.

44. We have advanced the thought that this might be an iron of an eutectic nature because it has a very narrow freezing range. Evidently the range is so narrow that the volume decrease between the liquid and the solid state does not occur in one spot (as a shrinkhole), owing to lack of time, but is disseminated throughout the entire casting. A discussion of this paper from the eutectic standpoint would be most enlightening to the author.

DISCUSSION

ORAL DISCUSSION

MEMBER: What was the silicon content of these two mixtures?

H. H. JUDSON: The silicon ranges from 1.5 to 1.6 per cent. It does not seem to make a great deal of difference if we do have varying silicon content. We can run it from 1.4 to 1.7 per cent and this variation does not affect the strength very much. Why, I do not know.

FRITZ MEYER:¹ It is the first time I have heard of the experiences indicated by the author, and I am quite astonished to note that he has

¹ Consultant, Rockford, Ill.

such low shrinkage with a low-carbon iron, especially since the silicon content is only 1.5 per cent. For the unusual experimental results reported I have no explanation. In general, we have always found that low-carbon iron gave us trouble with high shrinkage and forced us to apply heavy risers in order to make a solid casting.

I would like to give my point of view as to the influence of steel on the physical properties of low-carbon gray iron in the cupola. As a rule, steel is added to the cupola charge in order to keep the total carbon down, and to get closer grain structure whereby the increased physical properties are contributed entirely to the low carbon content through the steel addition.

I believe that is wrong. By the use of steel in the cupola, the charges (at any rate, the steel charges) are forced to hang above the melting zone until the higher melting point is reached. For this reason the temperature of the molten metal is increased, the steel passing through the melting zone down to the coke, being recarburized partly by the carbon monoxide and partly by direct absorption of carbon from the incandescent coke, and reaching a lower melting point than it had before it was recarburized. In other words, the mixture is superheated an amount which is the difference between the melting point of steel before and after recarburization.

Steel has no graphite to be dissolved. The difficulty of dissolving the graphite flakes in the cupola due to the comparatively short period of time that the iron remains at top temperature in the melting zone, is the reason why cupola iron of a certain analysis always will have lower physical properties than an iron made in an electric furnace, air furnace, rotary powdered-coal furnace, or other types of furnaces permitting the iron to remain at top temperature until all the graphite flakes are dissolved. Cupola iron will show coarser graphite at the same pouring temperature.

This condition is remarkably improved by the addition of steel to the cupola, although we never will have the same ideal conditions as in the other types of furnaces mentioned. If no steel is in the mixture, there is a greater percentage of graphite to be dissolved, and if temperature and time do not permit the complete solution of graphite particles, the few undissolved flakes are present as nuclei when solidification starts. The result will be that these nuclei are building up the large graphite flakes. On the other hand, if complete solution of the graphite particles has taken place, a great number of nuclei are thrown out at once.

Suppose that two mixtures of the same analysis start to solidify, the first having only a few graphite nuclei present, the second having no graphite nuclei present at the start but acquiring a great number at once. The first mixture would have in final form large graphite flakes, and the second would have finely precipitated graphite even if the percentage of graphite in both cases is the same. The second would have higher strength also. Of course, the matrix is not interrupted by large graphite flakes, which weaken the structure.

MEMBER: Does the author regulate pouring time of these castings, and is the pouring time any slower on this high-test iron than for his

ordinary strength irons? We might account for the lack of shrinkage if the pouring is slow.

H. H. JUDSON: We use standard gating practice when pouring this grade of iron. The pattern, gate and riser equipments are the same as those used when the same jobs are poured from a single-cupola iron.

MEMBER: What are the sizes of the largest heats made when using this two-cupola process?

H. H. JUDSON: We have taken heats up to 8 tons that way, that is, running with a ratio of 2000 lbs. of soft iron to upward of 7500 of the hard iron. This is in the proportion for our line-pump cylinders.

MEMBER: Is there any difference in the flux used for the soft iron mix and that for the low-carbon mix?

H. H. JUDSON: We use straight limestone in both cases.

MEMBER: Was there any difference in the grain size of the irons produced by these two methods?

H. H. JUDSON: In regard to grain of the two-cupola iron, we have blown up full-size cylinders in check tests and have further broken these fragments into small pieces, searching for internal defects. One thing we noticed immediately, with the naked eye, was that there seemed to be no difference in the grain size from mold surface to core surface. Whether the section was 2 in. or 3 in. or 4 in., the grain size seemed to be remarkably uniform from edge to edge. When the iron was melted by the one-cupola process, the grain size increased from edge to center.

MEMBER: Do you find a large grain size associated with cavities and internal shrinks, and a close grain associated with sound castings?

H. H. JUDSON: I believe those conditions will be found in any casting. We do.

D. P. SPENCER:² I gather that the speaker attaches some importance to the reduced volume of air—that is, at the tuyeres—as affecting the degree of shrinkage and the necessity, in the first case, for maintaining the larger riser. I believe a good many of us here still are wondering how it is possible to eliminate risers with a mixture such as the speaker mentioned, even in castings of the cross-section stated. Is there not a growing belief that the degree of absorbed gases, whether oxygen, nitrogen or what not, may have more effect on shrinkage than the composition of total carbon or silicon?

H. H. JUDSON: The point is this: We did not reduce the blast. What we did was prevent it from increasing. As the heat progressed, the resistance offered to the blast through the cupola decreased, hence the blower motor would speed up. As soon as this happened, the blast volume curve would begin to climb, but we would immediately bring the blower speed back to a point that would bring the volume down to the proper quantity. In other words, instead of starting the heat with a

² Metallurgist, Racine Steel Castings Co., Racine, Wis.

blast volume of 5400 cu. ft. per minute and letting it increase to 5800 or 5900 cu. ft. per minute at the end of the heat, we started with a volume of 5400 cu. ft. per minute and held it there.

I quite agree with Mr. Spencer on the thought of absorbed gases. Many so-called shrink-holes and draws that are charged against the metal are due to faulty melting, molding and core-making practice. The mixture that is being used must have been satisfactory at some time, or else it would not have been used. The metal—i.e., analysis—should not be blamed until one is certain that the molding and core-making practices are right, as well as the melting practice.

The molds and cores must be made of free-venting materials with a sufficient number of efficient vents in both molds and cores. It might be well, as a sort of experiment, to lean over backward on the venting question and make up special molds, preferably in dry sand, and cores from exceptionally open sands, and vent them abnormally. Then pour them with the iron that is giving trouble. If the shrink or draw still persists, investigate the melting practice. By that time the trouble probably will have disappeared.

I do not think that many of the internal defects are caused by gases introduced either during the melting process or from the molds and cores. I think that cast iron shrinks, especially in the heavy sections, but the shrinkage can be minimized by the use of suitable mixtures and feeding practice. If a job has a tendency to shrink, gas introduced during the melting process, or from the mold and cores, will aggravate the tendency and produce an internal cavity that is called a shrink-hole but is really a gas pocket.

CHAIRMAN H. BORNSTEIN:² Mr. Judson mentioned the fact that he took a test bar right out of the casting and from the center of the 2½-in. section. What size bar was that?

H. H. JUDSON: The regular A. S. T. M. tensile coupon, 8/10 in. in diameter.

CHAIRMAN H. BORNSTEIN: It is interesting to note that the author, with a test bar from a very heavy section, secured a tensile strength in the neighborhood of 50,000 lbs. A good many of the so-called high-strength irons will give 50,000 lbs. when poured in the regular arbitration bar; yet, using this same iron in a 2-in. section casting and taking a test bar from the casting, one might get only 35,000 lbs. Thus, the author's iron is a super-high-strength iron.

MEMBER: What would the author's iron test under arbitration test bar conditions?

H. H. JUDSON: A separately cast standard bar with diameter of 1¼ in. tested transversely on 12-in. centers, will average slightly over 5000 lbs. Our testing machine has a capacity of 5000 lbs., and very often we cannot break the bars.

MEMBER: What would be the tensile test figures for your iron on separately cast test bars?

² Director, Testing and Research Laboratories, Deere & Co., Moline, Ill.

H. H. JUDSON: We have not made tensile tests on specimens cut from separately cast test bars for such a long time that I cannot give the data requested. We have no use for such test bars at all. They do not tell us anything, and we have found them misleading.

MEMBER: I am glad Mr. Judson brought out that point because, after all, we are selling castings and not test bars. I was interested to see, in terms of the test bar, whether or not the iron was so hard that it would make a weak test bar and, therefore, in a heavy-section casting would give the high strength.

H. H. JUDSON: In that connection, a test bar did serve us once; it showed a white skin with mottled iron reaching in toward the center, so that we knew something was wrong in the cupola. Somehow or other the crew got mixed up in the charging and put the ferrosilicon up on top and it did not get into the iron.

When the iron is right, a standard A. S. T. M. 1¼-in. diameter arbitration bar, cast in dry sand, is gray throughout.

Introduction to Final Report on Volume Changes of Cast Iron During Casting

The work reported in the paper* by C. M. Saeger, Jr. and E. J. Ash is, in the opinion of your Committee, the conclusion of the most important body of research work done by the American Foundrymen's Association since the development of suitable methods of test for foundry sand, and it deserves to rank with that work in importance.

The general subject of "Pig Iron Quality" was discussed¹ at Chicago in 1927, and occupies 37 pages of our *Transactions* for that year. It was continued at a joint round-table conference² of the A. F. A. and the A. I. M. E. in New York in 1928, which discussion required 14 pages of small type to cover.

The general consensus of opinion was that suitable tests should be devised to show the quality of the iron. This job was put in the hands of this Sub-Committee on Research of the A. F. A. Gray Iron Division, which most fortunately found the Bureau of Standards in a sympathetic frame of mind and, through its assistance, was able to get the work started.

Properties of cast iron were listed and reported³ to the Association in 1929. This list required 7 pages for its presentation, without discussion. However, the two conferences mentioned above had emphasized the big gap in the then existing test procedure, which were:

Measurement of Liquid Temperatures.

Fluidity or Life of the Molten Iron.

Shrinkage or Change in Volume during Freezing.

The temperature problem had been attacked already by the Pyrometry section of the Heat and Power Division of the Bureau, and this problem was practically solved by a report of an

* See page 172.

¹ Conference on the Qualities of Pig Iron for Castings Purposes, TRANSACTIONS A. F. A. (1927), vol. 35, pp. 328-355.

² "Blast Furnace Operation and the Character of Pig Iron and Castings," *Iron and Steel Technology in 1928*, pub. by A. I. M. E. for Iron and Steel Division, 1928.

³ *Properties of Cast Iron of Interest to the Metallurgist, Founder and Engineer*, TRANSACTIONS A. F. A. (1929), vol. 37, pp. 331-342.

investigation the results of which were given in a paper⁴ by Wensel and Roeser, presented at Philadelphia in 1928. It showed the confusing action of surface films in the most important part of the temperature scale and its vitiating effect on the optical pyrometer readings, which no doubt accounts for much of the confusion in published temperatures.

The authors, however, devised a thoroughly practical (although expensive) thermocouple set-up for accurate measurements so that this need no longer be a bar to the foundryman. In fact, their determination of the range in which these optical effects occur, and their clear statement of the phenomena causing them, have enabled the experienced observer to correct his optical readings quite accurately.

The problem of "fluidity" or "life" of the metal had been attacked by several investigators, but probably the best form of test was that used by Curry as reported⁵ at the 1927 meeting of the A. F. A. This was a modification of the spiral proposed by Saito and Hayashi in 1919.

With this as a basis, the Foundry section of the Division of Metallurgy of the Bureau, under Mr. Saeger, set about studying the influence of the different variables on this test and found that it was not yet suitable for accurate work. They designed a highly satisfactory modification which was published⁶ in 1931, so that this second problem also was solved.

The problem of shrinkage during solidification was attacked through the Research Associate plan. E. J. Ash was placed with Mr. Saeger at the Bureau and worked for some time on the problem, using the ideas of Schwartz' pear-shaped specimen,⁷ and later a standard size cone. It proved to be quite difficult to get checks of the order of accuracy demanded. Thus, it was apparent that some other method would have to be used, the idea being that an accurate measure, at any cost, must be obtained before we could evaluate properly any simple shop method. The method de-

⁴ Wensel H. T. and Roeser, W. F., *Temperature Measurements of Molten Cast Iron*, TRANSACTIONS A. F. A. (1928), vol. 36, pp. 191-212.

⁵ Curry, C., *Test Bars to Establish the Fluidity Qualities of Cast Iron*, TRANSACTIONS A. F. A. (1927), vol. 36, pp. 289-305.

⁶ Saeger, C. M., Jr. and Krynitsky, A. I., *A Practical Method for Studying the Running Quality of a Metal Cast in Foundry Molds*, TRANSACTIONS A. F. A. (1931), vol. 39, pp. 513-532.

⁷ Schwartz, H. A., *Shrinkage in White Cast Iron*, TRANSACTIONS A. F. A. (1929), vol. 37, p. 222.

scribed in the preliminary report⁸ and the following paper* seems to have fulfilled its purpose and, in conjunction with their apparatus for solid contraction, gives us a powerful tool for the study of metals for casting.

It is with regret, however, that we must say that we cannot yet consider this third problem completely solved. The problem of "draws" in the foundry is extremely complicated, and the determination of volume changes is only one phase of it. A practical shop method is needed because it is not proven that all irons will behave as these authors have indicated⁹ in their "shop method," i.e., according to the percentages of metalloids.

Also, the work of the authors on two sizes of contraction specimens shows what a complicated system we are dealing with when making a casting of varying section. Even in a comparatively uniform casting, one part may be liquid, one part expanding, and still another contracting. Many factors will enter the problem—especially thermal conductivity, gas evolution, presence of primary graphite and especially undissolved graphite, phosphorus, and, most important of all, the character of the mold, position and size of gates and risers, speed of pouring, etc. As far as the original purpose of the work is concerned, i.e., evaluation of pig iron, we may consider this point settled although each casting still will be a problem in the foundry.

It is interesting, however, to note that a great deal of information can be obtained from the contraction curves. With these on several pertinent sizes of test bars, much of our present grief from warping and casting strains may be studied and remedied. For example, a metal that would give the least difference in its contraction curves between a large and a small bar, probably would make the best casting of two such sections, even though it might not be so strong, in a separately cast bar, as another metal.

In concluding these remarks, the Committee desires to express its deep appreciation to Messrs. Wensel and Roeser of the High-Temperature section, and to Dr. Mueller and Dr. Dickinson

⁸ Saeger, C. M., Jr. and Ash, E. J., *Methods for Determining the Volume Changes Undergone by Metals and Alloys During Casting*, TRANSACTIONS A. F. A. (1931), vol. 39, pp. 107-145.

* See page 172.

⁹ Ash, E. J. and Saeger, C. M., Jr., *Shop Method for Determining Volume Changes in Cast Iron During Casting*, Preprint 32-5, American Foundrymen's Association 1932 Convention. See also page 168 of the present publication.

of the Heat and Power Division; to Messrs. Ash, Krynitsky and Saeger of the Foundry section; to Dr. H. W. Gillett, who was chief of the Division of Metallurgy at the beginning of this work, and to Dr. H. S. Rawdon, present chief of the division; and finally, for his guidance throughout the period of these tests, to the late Dr. G. K. Burgess, Director of the Bureau, whose recent death was a shock to his friends and a distinct loss to the world of science.

JAS. T. MACKENZIE, *Chairman*

Sub-Committee on Research, A. F. A. Gray Iron Division.

(The report to which the preceding article is introductory, begins on the following page, 172.)

Volume Changes of Cast Irons During Casting*

By C. M. SAEGER, JR.† and E. J. ASH,** WASHINGTON

Abstract

The volume changes occurring in eight types of cast irons during cooling from the liquid state to room temperature, are given in this paper. The irons varied in composition from gray iron to white iron. The coefficient of volume shrinkage in the liquid state for the irons over the range of temperature studied was 0.011 per cent per degree Centigrade. The volume change during solidification varied from an expansion of 1.65 per cent in a gray iron to a contraction of 5.85 per cent in a low-carbon low-silicon type of iron. The linear contraction of the sand-cast bars varied inversely with the silicon and carbon content and also with the cross-sectional area. The lowest linear shrinkage value measured was 0.65 per cent (1 1/2-in. square bar), and the highest was 2.08 per cent (3/4-in. square bar). In both heating and cooling curves, and in the sand-cast contraction bars, a pronounced effect was observed at about 1070 degs. Cent., possibly indicative of some transformation. An expansion was observed at this temperature during the freezing of all melts of cast iron. This expansion, however, was not due to decomposition of cementite alone, for white iron bars having no free graphite present showed this same phenomenon. This expansion may have been caused by the separation of dissolved gases during solidification, as has been pointed out by previous investigators.

INTRODUCTION

1. The changes taking place in the linear dimensions of cast iron during cooling from the freezing range to room temperature, have been the subject of many investigations. Few

* Publication approved by the Director, Bureau of Standards, U. S. Department of Commerce.

† Physicist, U. S. Bureau of Standards.

** Research Associate representing the American Foundrymen's Association, at U. S. Bureau of Standards.

studies, however, have been made to determine the volume changes during cooling in the liquid state and during subsequent solidification.

2. This latter information is of fundamental importance to foundrymen in the design and production of sound castings. Its application to the determination of the size and position of gates and risers is essential for the production of castings free from shrink holes and porosity. That soundness of the cast metal is essential in the production of high-strength cast irons has been emphasized by Piwowarsky¹ and by many other foundry investigators.

3. In 1929 the Bureau of Standards, cooperating with the American Foundrymen's Association, undertook the development of a method for determining the volume changes occurring in cast irons during cooling from some temperature in the liquid state to room temperature. At the time this work was initiated, there were available reports on the determination of the specific volume of liquid cast iron by Benedicks and co-workers,² Desch and Smith,³ and Honda and Endo.⁴ Only Honda and Endo gave values for the volume change during solidification.

4. Recently three additional papers have been published dealing with the specific volume of liquid cast irons. Both Benedicks⁵ and Honda,⁶ with their co-workers, have extended their results over a wide range of irons. Widawski and Sauerwald⁷ determined the specific volume of a series of molten cast irons, making measurements up to 1600 degs. Cent. (2912 degs. Fahr.) Again, only Honda and his collaborators gave values for the volume change during solidification.

5. A preliminary report covering the early stages of the work at the Bureau of Standards on the volume changes of cast

¹ E. Piwowarsky, *Production of High-Test Cast Iron*, TRANSACTIONS A. F. A. (1926), vol. 34, p. 914.

² C. Benedicks, D. W. Berlin and G. Phragmen, "A Method For Determination of the Specific Gravity of Liquid Iron and Other Metals of High Melting Point," *Jour. Iron and Steel Inst.*, Carnegie Scholarship Mem., vol. 13, p. 129, 1924.

³ C. W. Desch and B. S. Smith, "Interim Report on the Density of Molten Steel," *Jour. Iron and Steel Inst.*, vol. 119, p. 538, 1929.

⁴ K. Honda and H. Endo, "On the Volume Change in Cast Iron during Solidification," *Sci. Reports*, Tohoku Imp. Univ., vol. 16, p. 19, 1927.

⁵ C. Benedicks, N. Ericsson and G. Ericson, "Bestimmung des Spezifischen Volumens von Eisen, Nickel und Eisenlegierungen im Geschmolzenen Zustand," *Archiv für das Eisenhüttenwesen*, vol. 3, p. 473, 1930.

⁶ K. Honda, T. Kase and Y. Matuyama, "On the Change of Volume of Cast Iron during Solidification," *Sci. Repts.*, Tohoku Imp. Univ., vol. 18, p. 699, 1929.

⁷ E. Widawski and F. Sauerwald, "Ueber die Direkte Auftriebsmethode und die Dichte Schmelzflüssiger Metalle, Insbesondere von Eisenlegierungen bei Temperaturen bis 1600°C," *Zeitschrift für Anorganische und Allgemeine Chemie*, vol. 192, p. 145, 1930.

irons was published in 1930.⁸ A detailed account of the method finally developed for determining the volume changes occurring during the casting of metals and alloys has recently appeared in the *Bureau of Standards Journal of Research*.⁹ The present paper gives the specific volume-temperature relations of a number of cast irons of varying composition on cooling from some temperature in the liquid state to room temperature.¹⁰

MATERIALS

6. Pig iron from three sources was used in the preparation of the cast iron melts. Pig iron "B," a soft gray iron, was taken from stock at the Bureau of Standards; pig iron "C," an iron of exceptionally uniform composition, all cast from a single ladle, was supplied through the courtesy of the Republic Iron & Steel Co., Birmingham, Ala.; pig iron "D," a white iron, was made available through the kindness of H. A. Schwartz of the National Malleable & Steel Castings Co., Cleveland, O.

7. The chemical composition of these pig irons is given in Table 2. Additions of commercial open-hearth ingot iron were made to the furnace charges when it was necessary to dilute the carbon, silicon and other constituents of the above irons.

APPARATUS AND PROCEDURE

8. The apparatus and methods used for determining the specific volume-temperature relations of metals have been described in detail in previous publications.^{8,9} The specific volume-temperature curves of liquid cast iron were constructed from data which were obtained by application of the crucible immersion method.

9. In this method a crucible of known volume is filled with liquid metal at a known temperature. The mass of this sample of metal is the same in the liquid phase as in the solid phase at room temperature. The specific volume of the liquid, therefore, can readily be calculated from the known volume of the crucible at

⁸ C. M. Saeger, Jr. and E. J. Ash, *Methods for Determining the Volume Changes Undergone by Metals and Alloys During Casting*, TRANSACTIONS A. F. A. (1930), vol. 38, p. 107.

⁹ C. M. Saeger, Jr. and E. J. Ash, "A Method for Determining the Volume Changes Occurring in Metals During Casting," *B. S. Jour. Res.*, vol. 8, p. 37, 1932.

¹⁰ This report is the basis for data presented in the paper, *Shop Method for Determining Volume Changes of Cast Iron During Casting*, by E. J. Ash and C. M. Saeger, Jr. (See page 188.)

the elevated temperature¹¹ and the weight of the solid metal sample.

10. Data on the contraction of the solid metal obtained by direct observations of the change in length with change in temperature of a sand-cast bar of metal, permitted calculation of the specific volume-temperature relation of the solid metal. The difference between the specific volume of the liquid metal and of the solid metal at the temperatures corresponding to the liquidus and the solidus, respectively, represents the volume change during solidification. The liquidus and solidus temperatures for each composition were determined by thermal analysis.

11. The observations on each heat of cast iron were made as follows: The charge of iron was melted in a high-frequency induction furnace and heated to a maximum temperature of 1500 degs. Cent. (2732 degs. Fahr.) for gray iron and 1600 degs. Cent. (2912 degs. Fahr.) for white iron. Temperatures were measured by means of a platinum to platinum-rhodium thermocouple.

12. When the melt had reached the desired maximum temperature, the power input was reduced sufficiently to permit cooling of the melt, but at a retarded rate, and also to continue a slow stirring action of the bath. The first liquid sample was then taken.

13. Sufficient metal was then transferred to a preheated crucible for casting the solid contraction bars and a small ingot for subsequent determination of the freezing range. Additional liquid samples were taken as the metal cooled in the furnace.

14. After the samples of liquid metal had cooled to room temperature, the ingots were removed from the crucibles and weighed and the specific volume of the liquid metal was calculated for each sampling temperature. The specific volume-temperature curve of the liquid metal was made from these data.

15. In order to study the effect of cross-sectional area on the volume changes of cast iron, two sizes of bars—one 3/4 in. square and the other 1 1/2 in. square, both 12 in. long—were poured from each melt.

¹¹ The calculation of the volume of the crucible at the elevated temperature depends on the coefficient of thermal expansion of graphite. The value of this coefficient used in this report was obtained by extrapolation of experimental data from 600 degs. Cent. (1112 degs. Fahr.) to the temperatures of molten cast iron. Recently, however, this coefficient up to 1000 degs. Cent. (1832 degs. Fahr.) has been determined at this Bureau. Use of these later data shortens considerably the necessary extrapolation for obtaining the thermal expansion of graphite at the higher temperatures. Specific volumes calculated on the basis of the recent data confirm the validity of the earlier calculations.

Table 1
MATERIALS CONSTITUTING CHARGES

Melt No.	Lot	Pig Iron		Open-Hearth Iron		Other Additions
		Weight, Lbs.	Proportion of Charge, per cent	Weight, Lbs.	Proportion of Charge, per cent	
I	B	97	100	.....	.....
II	B	105	100	.....	.....
III	B	120	80	30	20	
IV	B	96	80	24	20	
V	B	72	60	48	40	
VI	B	78	60	52	40	
VII	B	125	100	.....	.....
VIII	C	125	100	.....	.....
IX	C	125	100	.....	.....
X	D	115	100	.....	.....
XI	D	140	100	.....	.....
XII	D	140	100	.....	.....	{ 1.4 lbs. FeSi,* 0.5 lbs. FeMn†
XIII	C	130	90	13	10	{ 2.0 lbs. FeSi, 0.2 lbs. FeMn, 0.8 lbs. FeP**
XIV	C	127	80	32	20	{ 0.75 lbs. FeSi, 0.1 lb. FeMn, 0.4 lb. FeP

*FeSi—Ferro-silicon containing 50 per cent silicon.

†FeMn—Ferromanganese containing 80 per cent manganese.

**FeP—Ferrophosphorus containing 25 per cent phosphorus.

Table 2
COMPOSITION OF CAST IRON MELTS*

Melt No.	Si	Mn	P	S	½-In. Sq. Bar		1½-In. Sq. Bar	
					Total Carbon, per cent	Graphitic Carbon, per cent	Total Carbon, per cent	Graphitic Carbon, per cent
I	2.08	0.50	0.44	0.05	3.63	2.99	3.63	2.97
II	2.11	0.50	0.46	0.05	3.71	2.96	3.71	2.99
III	1.68	0.44	0.35	0.04	3.08	2.23	3.08	2.18
IV	1.69	0.48	0.35	0.04	3.10	2.27	3.10	2.31
VI	1.24	0.35	0.27	0.04	2.29	0.42	2.18	0.56
VII	2.10	0.54	0.46	0.05	3.76	3.35	3.67	3.26
VIII	2.87	0.59	0.68	0.03	3.63	3.42	3.69	3.53
IX	2.86	0.58	0.67	0.03	3.60	3.40	3.39	3.20
X	0.84	0.24	0.15	0.06	2.00	.00	2.08	.00
XI	.85	0.25	0.14	0.06	1.96	.00	1.98	.00
XII	1.50	0.27	0.14	0.06	1.97	.00	1.87	0.01
XIII	2.87	0.52	0.59	0.03	3.27	2.90	3.27	2.88
XIV	2.88	0.44	0.66	0.03	2.89	2.65	2.90	2.68
Pig Iron:								
B	2.31	0.67	0.46	0.045	3.81	3.15	.....	.....
C	2.90	0.56	0.67	0.02	3.68	.....	.....	.....
D	1.00	0.29	0.15	0.06	2.07	.....	.....	.....

*Analyses made by R. H. Elders, American Cast Iron Pipe Co., Birmingham, Ala.

Table 3
SHRINKAGE DATA ON 14 CAST IRON MELTS

Melt Nos.	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV
Maximum heating temperature (Degs. Cent.)	1600	1400	1500	1500	1500	1500	1500	1500	1500	1500	1500	1600	1500	1500
Temperature of Liquides (Degs. Fahr.)	2912	2532	2732	2732	2732	2732	2732	2732	2732	2732	2912	2912	2732	2732
Specific volume* at 1150°C. (2102°F.), 1-in. bar.	0.1452	0.1453	0.1417	0.1420	0.1445	0.1442	0.1442	0.1441	0.1452	0.1452	0.1440	0.1438	0.1448	0.1440
Specific volume* at 1150°C. (2102°F.), 14-in. bar.	0.1448	0.1451	0.1422	0.1417	0.1372	0.1368	0.1368	0.1450	0.1453	0.1464	0.1360	0.1373	0.1374	0.1449
Density† at room temperature, 1-in. bar.	7.128	7.116	7.307	7.285	7.571	7.602	7.602	7.602	7.022	7.039	7.720	7.716	7.692	7.148
Density† at room temperature, 14-in. bar.	7.103	7.118	7.266	7.281	7.571	7.602	7.602	7.602	7.022	7.039	7.732	7.734	7.698	7.082
Specific volume* at room temperature, 1-in. bar.	0.1403	0.1405	0.1369	0.1373	0.1299	0.1305	0.1305	0.1410	0.1428	0.1420	0.1285	0.1296	0.1300	0.1412
Specific volume* at room temperature, 14-in. bar.	0.1408	0.1405	0.1376	0.1377	0.1321	0.1305	0.1305	0.1410	0.1424	0.1422	0.1285	0.1293	0.1299	0.1412
Avg. contraction of liquid per 100°C. (212°F.), per cent.	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Shrinkage during solidification (liquid to 1150°C.—2102°F.), per cent.	1.94	1.73	1.94	1.73	4.85	4.85	4.85	4.85	1.11	1.11	4.10	4.17	3.96	1.31
Shrinkage during solidification (liquid to 1150°C.—2102°F.), per cent.	1.59	1.94	1.59	1.94	4.85	4.85	4.85	4.85	1.11	1.11	4.10	4.17	3.96	1.31
Linear contraction from 1150°C. (2102°F.), per cent.	1.13	1.11	1.12	1.11	1.77	1.77	1.77	1.77	1.08	1.08	2.08	2.03	1.97	1.09
Linear contraction from 1150°C. (2102°F.), per cent.	1.06	1.08	1.08	0.95	1.23	1.31	1.31	0.83	0.67	0.97	1.83	1.95	1.81	0.98
Linear contraction from 1070°C. (1958°F.), per cent.	1.25	1.22	1.22	1.22	1.14	1.17	1.17	1.19	1.19	1.19	2.08	2.00	1.13	1.21
Linear contraction from 1070°C. (1958°F.), per cent.	1.13	1.24	1.19	1.19	1.04	0.90	0.90	1.12	1.12	1.12	1.75	1.91	1.03	1.17

*In cubic centimeters per gram.

†In grams per cubic centimeter.

16. The temperature range of solidification was determined by thermal analyses of the small ingot cast for this purpose.

RESULTS

17. The shrinkage characteristics were determined for 14 melts of cast iron, representing eight different compositions. The material making up each charge is given in Table 1. The results of chemical analyses of each of the 14 melts and of the three pig irons used in making up the charges are given in Table 2. A summary of the shrinkage data obtained is given in Table 3.

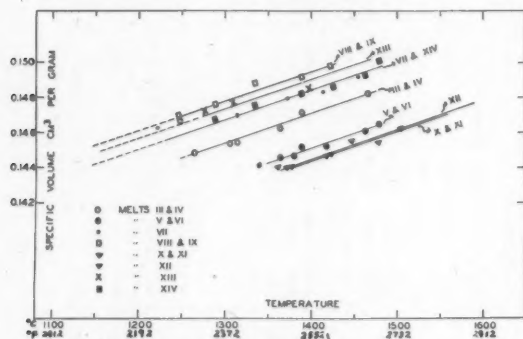


FIG. 1—SPECIFIC VOLUME-TEMPERATURE CURVES OF CAST IRONS IN THE LIQUID STATE.

1—Specific Volume-Temperature Curves

(a) Liquid.

18. Fig. 1 shows the relation between specific volume and temperature of the liquid metal for 12 melts of cast iron. Cast irons having relatively high carbon and silicon contents (melts VII, VIII, IX, XIII and XIV) have greater specific volumes at a given temperature than the cast irons with lower carbon and silicon contents.

19. Repeated heating and cooling of liquid cast iron indicated no measurable change in the specific volume of the metal. The results of a study of this nature are shown in Fig. 2.

20. This metal was heated to a maximum temperature in

the furnace, poured into a crucible, and four liquid samples were taken as the metal cooled. The remaining metal in the crucible was returned to the furnace, reheated to a maximum temperature, again poured into the crucible, and four additional liquid samples were obtained as the metal cooled.

(b) *Solid.*

21. The linear contraction-temperature curve of each com-

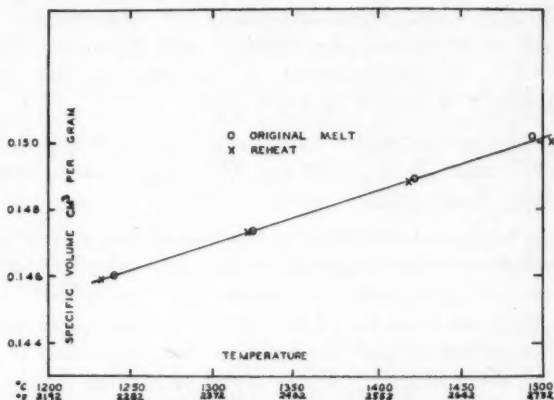


FIG. 2—SPECIFIC VOLUME-TEMPERATURE CURVE OF A LIQUID CAST IRON AFTER REPEATED HEATING AND COOLING.

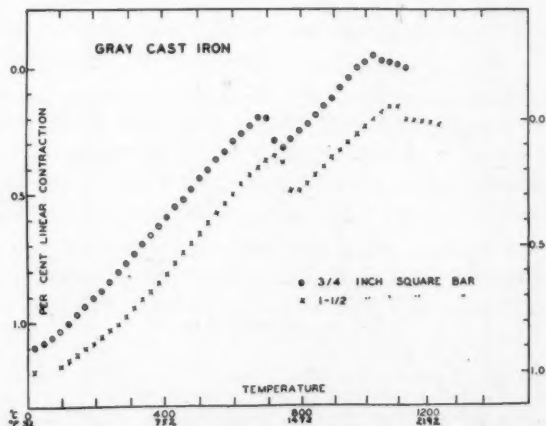


FIG. 3—LINEAR CONTRACTION-TEMPERATURE CURVE OF A GRAY CAST IRON.

position of cast iron in the solid state was obtained by plotting observed changes in length with change in temperature of the cast bars referred to previously. Fig. 3 shows a contraction curve for a typical gray cast iron.

22. In general, all gray cast irons undergo an expansion during or immediately after solidification. The initial expansion indicated by the bar begins at a temperature above 1130 degs. Cent. (2066 degs. Fahr.) and reaches a maximum at approximately 1070 degs. Cent. (1958 degs. Fahr.) This expansion is also characteristic of white cast iron (Fig. 4) and hence, should not be attributed to the decomposition of the cementite because no primary graphite is formed in white iron.

23. A comparison between the linear shrinkage values from 1150 and 1070 degs. Cent. (2102 and 1958 degs. Fahr.), respectively, to room temperature is given in Table 3.

24. As the specific volume (or density) of cast iron at room temperature varies with composition and with rate of cooling, the density was determined on each bar. Specimens 1/2-in. thick, cut from the free end of the contraction bar, were considered to be representative of the metal in that bar. This experimental value for the density of the metal of a given contraction

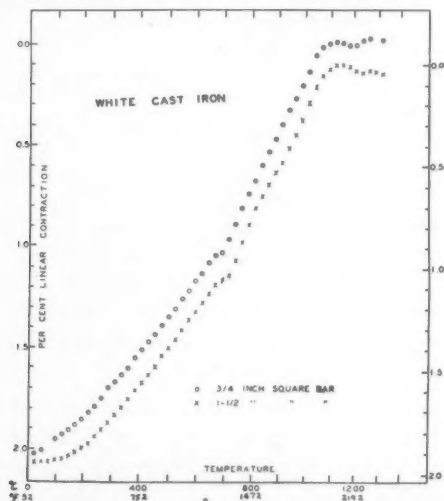


FIG. 4—LINEAR CONTRACTION-TEMPERATURE CURVE OF A WHITE CAST IRON.

bar at room temperature, together with the observed changes in linear dimensions of the bar during cooling from the freezing range, permitted the calculation of the specific volume of the solid metal throughout the range from the temperature of complete solidification to room temperature.

25. The expansion phenomenon associated with freezing of cast irons has been observed by a number of investigators. Bardenheuer and Ebbefeld¹² have attributed this expansion to the release of gases during the transition from fluid to the solid state. This view is in agreement with Boehm,¹³ who observed a similar phenomenon for copper-tin alloys.

26. Piowarsky¹ reported a relation between the amount of gas released during solidification and the temperature to which the cast iron had been superheated. He reported the amount of gas given off by a series of cast iron melts as varying from 1.12 to 2.74 cu. in. per lb. of metal. The gas liberated was composed of CO, CO₂, H₂, N₂ and CH₄. He concluded that this observed expansion at the end of the freezing range was detrimental to the metal, inasmuch as it decreased its density.

2—Solidification Range

27. For the present investigation, because the evaluation of the volume change during solidification depended on the specific volume change between the liquidus and solidus, the extent of the freezing range was determined for each cast iron studied. Typical inverse rate heating and cooling curves for a gray cast iron are shown in Fig. 5.

28. There was a break in the time-temperature curve on cooling at about 1147 degs. Cent. (2097 degs. Fahr.) which was taken as an indication of the liquidus. On heating, the break in the time-temperature curve was consistently found at about 1070 degs. Cent. (1958 degs. Fahr.), the temperature of the solidus.

29. A heating and a cooling curve for a white cast iron are given in Fig. 6. The liquidus is indicated at 1380 degs. Cent. (2516 degs. Fahr.) and the solidus at 1063 degs. Cent. (1963 degs. Fahr.)

¹² P. Bardenheuer and C. Ebbefeld, "Beitrag zur Analyse des Schwindungsvorganges von Weissm und Grauem Gusseisen," *Stahl und Eisen*, 45, pp. 825 and 1022; 1925.

¹³ F. Boehm, "Ueber die Schwindung von Legierungen," *Dissertation*, Technischen Hochschule zu Breslau, 1930.

30. The occurrence of an apparent solidus at about 1070 degs. Cent. (1958 degs. Fahr.) was typical of every cast iron composition studied. Thermal analyses of specimens of different sizes also indicated this thermal change at approximately 1070 degs. Cent. (1958 degs. Fahr.), both on heating and cooling.

31. This deviation of the cooling curve at about 1070 degs. Cent. (1958 degs. Fahr.) appears to be more pronounced in those cast irons containing higher amounts of combined carbon. Thus, in Fig. 7, the cooling curve of melt No. VI shows a very distinct halt at approximately this temperature. This also is observed in white cast iron (see Fig. 6).

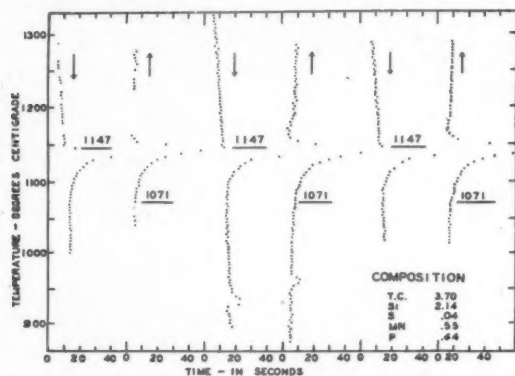


FIG. 5—INVERSE RATE HEATING AND COOLING CURVES OF A GRAY CAST IRON.

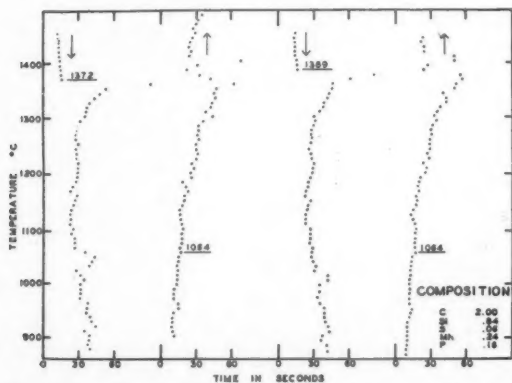


FIG. 6—INVERSE RATE HEATING AND COOLING CURVES OF WHITE CAST IRON.

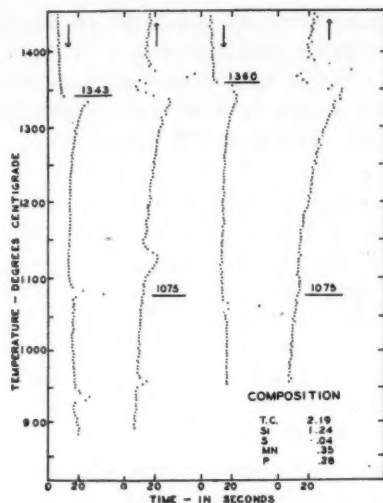


FIG. 7—INVERSE RATE HEATING AND COOLING CURVES OF A CAST IRON DILUTED WITH 40 PER CENT COMMERCIAL OPEN-HEARTH INGOT IRON.

32. The temperature of the occurrence of the maximum expansion of the solid contraction bars coincides with the observed temperature of the apparent solidus for these irons. Because of the complex nature of cast iron, this temperature may represent the change of state of a low melting material (eutectic) formed from the various constituents in the material.

33. The change of structure occurring at 1070 degs. Cent. (1958 degs. Fahr.) is not very great because the amount of heat evolved or absorbed at this temperature appears to be small. If this expansion phenomenon is due to the separation of occluded gases, the material could not possibly be completely solid until after the maximum expansion had taken place.

34. Hanson¹⁴ states: "that portion (of the iron-carbon diagram) down to and including the eutectic represents an iron-graphite system, but at some temperature below the eutectic line the alloys undergo transformations according to the system iron-cementite." In the diagrams referred to in his statement, the *Acm* line was not connected with the eutectic horizontal.

¹⁴ D. Hanson, "The Constitution of Silicon-Carbon-Iron Alloys and a New Theory of the Cast Irons," *Jour. Iron and Steel Inst.*, vol. 114, p. 129, 1927.

35. The data of the present investigation are considered insufficient for identifying the temperature of 1070 degs. Cent. (1958 degs. Fahr.) as the true solidus of these cast irons. The solidus of cast iron usually is considered to occur between 1130 and 1150 degs. Cent. (2066 and 2102 degs. Fahr.), depending on the composition.

36. Temperature-contraction data of the present investigation indicated that at 1150 degs. Cent. (2102 degs. Fahr.) the bars had not, in general, moved appreciably. However, at 1130 degs. Cent. (2066 degs. Fahr.), the temperature at which the next observation was made, the free ends of the bars were in motion. Since it was desired to select the solidus at or just above the temperature representing initial movement in the solid bar, the temperature—1150 degs. Cent. (2102 degs. Fahr.)—was chosen as the solidus point for all irons.

37. The specific volume-temperature relations for a cast iron from some temperature in the liquid state to room temperature can be plotted on a single curve. Such curves for three cast irons are shown in Fig. 8.

38. These melts (see Table 1) were made from the same lot of pig iron, but two contained different proportions of open-hearth iron. Melt VII was all pig iron "B;" melt IV was 80 per cent pig iron "B" and 20 per cent open-hearth iron; melt VI

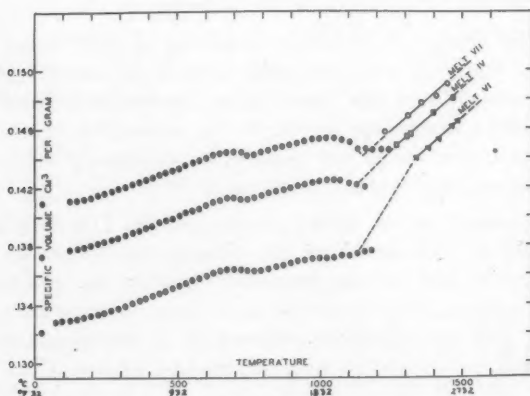


FIG. 8.—COMPLETE SPECIFIC VOLUME-TEMPERATURE RELATIONS FOR THREE COMPOSITIONS OF CAST IRON.

was composed of 60 per cent pig iron "B" and 40 per cent open-hearth iron. The effect of decreasing amounts of carbon, silicon and other constituents on the shrinkage characteristics of cast iron, is shown in this figure.

39. The complete shrinkage data for a typical white cast iron (melt XI) are represented in Fig. 9.

40. In Fig. 10 the volume change during solidification of the cast irons studied in this investigation is plotted against the amount of graphitic carbon contained in the solid contraction bars. For purposes of comparison, there are plotted in the same manner the values obtained by Honda and his co-workers^{4, 6} on

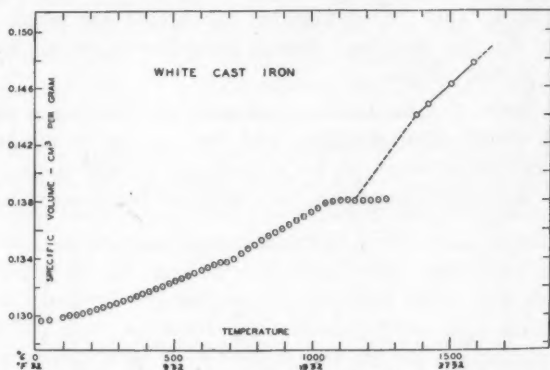


FIG. 9—COMPLETE SPECIFIC VOLUME-TEMPERATURE CURVE TYPICAL OF WHITE CAST IRON.

cast irons differing widely in composition from those used in this investigation.

41. The values obtained by Honda, by means of thermo-balance, indicate volume decreases during solidification appreciably smaller than those determined in the present study. Two factors may be suggested as quite probably contributing to the differences between Honda's data and the results of the present work, as follows:

(a) In the present study, the volume change during solidification has been defined^{8, 9} as the change in volume in passing from the liquid state at the beginning of the freezing range to the solid state at the end of the freezing range. In alloys hav-

ing a freezing range, as in many cast irons, the shrinkage during solidification includes, therefore, not only shrinkage resulting from the change of state, but also the shrinkage of the liquid and of the solid metal occurring within the range of solidification. The values given by Honda for shrinkage during solidification represent only the volume change resulting from the change of state. They should be expected, therefore, to be less than the values obtained in the present work.

(b) In a previous publication⁸ it has been pointed out that volume changes during solidification may not be measured accurately by the thermo-balance, owing to the very great probability of the formation of internal shrinkage cavities in the specimen during the change of state. Internal voids, whether localized in a "pipe" or distributed throughout the metal, result in values for the shrinkage during solidification which are less than the correct values.

42. Both of these factors, therefore—the difference in definition of solidification shrinkage and the liability of the thermo-balance method to errors caused by porosity—would tend to make Honda's shrinkage values less than those of the present work.

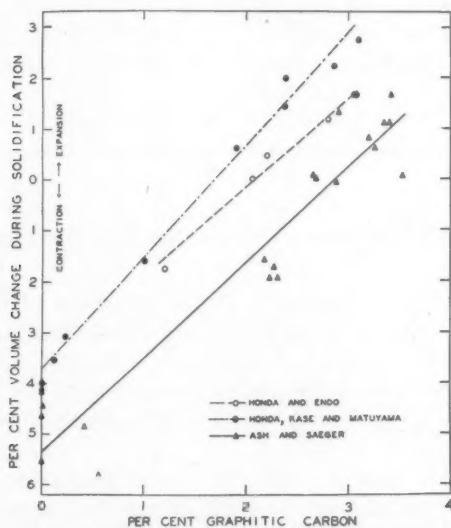


FIG. 10—RELATIONS BETWEEN THE VOLUME CHANGE DURING SOLIDIFICATION OF SOME CAST IRONS AND THE GRAPHITIC CARBON CONTENT.

SUMMARY

43. The volume changes occurring in eight types of cast irons during cooling from the liquid state to room temperature are given in this paper. The irons varied in composition from gray iron to white iron.

44. The coefficient of volume shrinkage in the liquid state for the irons over the range of temperature studied was 0.011 per cent per degree Centigrade. The volume change during solidification varied from an expansion of 1.65 per cent in a gray iron to a contraction of 5.85 per cent in a low-carbon low-silicon type of iron.

45. The linear contraction of the sand-cast bars varied inversely with the silicon and carbon content and also with the cross-sectional area. The lowest linear shrinkage value measured was 0.67 per cent (1 1/2-in. square bar), and the highest was 2.08 per cent (3/4-in. square bar).

46. In both heating and cooling curves and in the sand-cast contraction bars, a pronounced effect was observed at about 1070 degs. Cent. (1958 degs. Fahr.), possibly indicative of some transformation. An expansion was observed at this temperature during the freezing of all melts of cast iron. This expansion, however, was not due to decomposition of cementite alone, for white iron bars having no free graphite present showed this same phenomenon. This expansion may have been caused by the separation of dissolved gases during solidification, as has been pointed out by previous investigators.

ACKNOWLEDGMENTS

47. This investigation was sponsored by the American Foundrymen's Association from 1929 to 1931, and the authors wish to express their appreciation to the members of the Committee on Gray Cast Iron of the above association and particularly to J. T. MacKenzie, Chairman of the Research Committee, for his aid and counsel throughout this investigation.

48. Much credit is due L. D. Jones of the Foundry Section, who has done commendable work, and also to A. I. Krynitsky, C. B. Riecks, C. E. Jackson and H. B. Gardner, who rendered valuable assistance.

Shop Method for Determining Volume Changes in Cast Iron During Casting*

By E. J. ASH,[†] and C. M. SAEGER, JR.,** WASHINGTON

Abstract

A method for rapidly determining the volume changes occurring in cast iron during casting is outlined in this paper. The procedure is based upon the composition and linear contraction of the metal and the use of three charts. These charts represent a compilation of data from 12 melts of cast iron varying in composition from gray to white cast iron. The applicability of the method is illustrated by calculating the volume changes of a typical gray cast iron.

I—INTRODUCTION

1. The Bureau of Standards, in cooperation with the American Foundrymen's Association, has recently made a study of methods for the determination of the volume changes in metals during casting. The factors involved in the shrinkage of metals, methods used by other investigators, the methods used and the data obtained on the volume changes of a number of nonferrous metals and a series of cast irons, have been presented previously.^{1,2,3}

*Publication approved by the Director of the Bureau of Standards, U. S. Department of Commerce.

[†] Assistant Scientist, U. S. Bureau of Standards.

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¹ C. M. Saeger, Jr., and E. J. Ash, *Methods for Determining the Volume Changes Undergone by Metals and Alloys During Casting*, TRANSACTIONS A. F. A. (1930), vol. 38, p. 107.

² C. M. Saeger, Jr., and E. J. Ash, "A Method for Determining the Volume Changes Occurring in Metals During Casting," *B. S. Jour. Research*, vol. 8, p. 67, 1932.

³ E. J. Ash and C. M. Saeger, Jr., "Volume Changes of Cast Irons During Casting," *B. S. Jour. Research*, vol. 8, 1932.

NOTE: This paper was presented and discussed before one of the sessions on gray iron at the 1932 convention of the American Foundrymen's Association.

2. It was pointed out that most of the unsoundness in a casting is produced during the solidification of the metal.¹ Alloys having a long freezing range and large volume change during solidification are more susceptible to shrink holes and porosity, and more care is required in the gating and feeding of such alloys, than in those having a relatively short freezing range and small volume changes during solidification. A knowledge of the volume change during solidification of the metal is essential to the production of sound castings.

3. The over-all shrinkage of a metal cooling from the liquid to the solid state at room temperature can be divided into three parts, (1) shrinkage in the liquid state, (2) shrinkage during solidification, and (3) shrinkage in the solid state. This is illustrated in Fig. 1, which shows the volume changes in a typical white cast iron determined by the method previously described.^{2,3} These volume changes were calculated from the specific volumes at the various temperatures.

4. The determinations of the specific volume of cast iron at elevated temperatures requires careful manipulation. Consequently, an indirect method based upon data obtained in the previous study of 12 commercial cast irons has been developed, by means of which it is believed volume changes in irons during

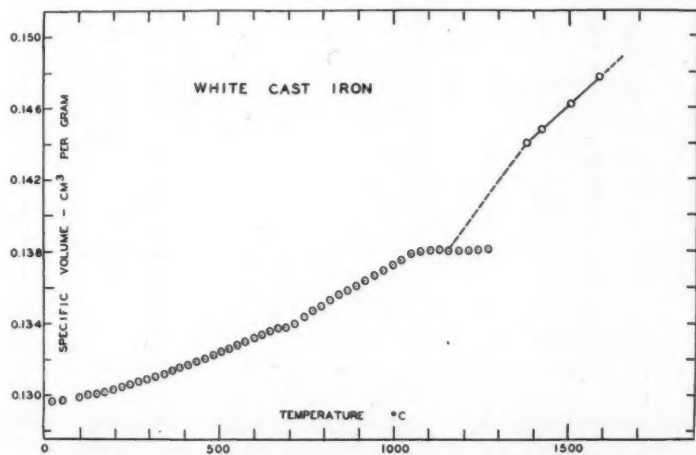


FIG. 1.—SPECIFIC VOLUME-TEMPERATURE RELATION OF A WHITE CAST IRON.

casting can be determined in the foundry quickly and with sufficient accuracy for all practical purposes. The composition of the cast iron and the linear contraction in cooling from the freezing temperature to room temperature are all that need be determined in the foundry.

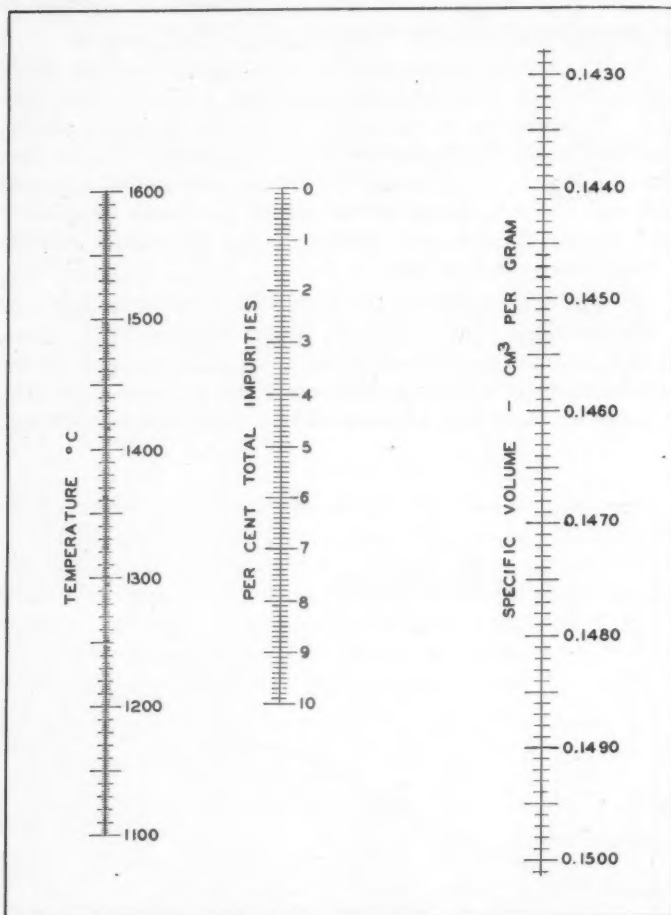


FIG. 2—ALIGNMENT CHART FOR DETERMINING THE SPECIFIC VOLUME OF LIQUID CAST IRON.

II—METHOD

5. The successive volume changes undergone by a metal or alloy during casting are best expressed in terms of the changes in specific volume with change in temperature as the metal cools from the liquid state to room temperature. As the shrinkage of a metal during casting takes place in three stages, the method for determining the volume change during each stage will be considered separately.

6. The rate at which cast iron shrinks while in the liquid state can be determined by means of Fig. 2. This "alignment chart," or "nomograph," shows the relation between specific volume and temperature for irons of different amounts of "total impurities" and is based on the data obtained in the previous study of 12 commercial cast irons ranging from white to gray.

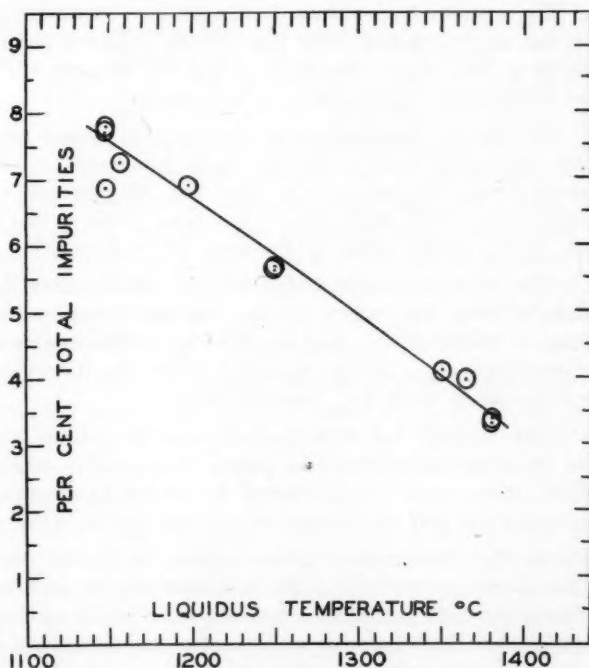


FIG. 3.—RELATION OF LIQUIDUS TEMPERATURE TO TOTAL IMPURITIES IN CAST IRON.

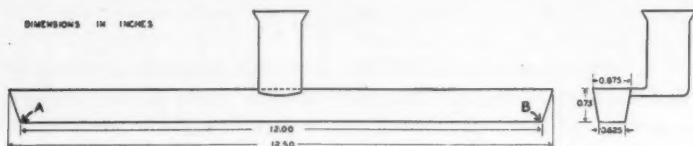


FIG. 4—BAR FOR DETERMINING TOTAL LINEAR CONTRACTION OF CAST IRON. THE DIMENSIONS GIVEN ARE ARBITRARY.

The term, "total impurities," is used throughout this paper to express the summation of common constituents of cast iron, carbon, silicon, phosphorus, manganese and sulphur.

7. Shrinkage in the liquid state, for a given cast iron, is determined by the difference in its specific volume at any temperature in the liquid state and at the liquidus temperature (beginning of freezing or solidification).

8. The liquidus temperature for a cast iron of known composition can be determined from Fig. 3 with sufficient accuracy. This curve is based upon the experimental determination of the liquidus temperature for 12 melts of cast iron.

9. The liquidus temperature for any cast iron whose amount of "total impurities" lies within the limits given can be readily determined from this curve. On the basis of previous work, 1150 degs. Cent. (2102 degs. Fahr.) has been taken as the temperature of the solidus (end of freezing) of cast iron.

10. The shrinkage taking place during solidification is the difference between the volume at the liquidus (temperature of beginning of solidification) and at the solidus (temperature of end of solidification). It is calculated from the difference in specific volumes at these two temperatures.

11. The method for obtaining the specific volume at the liquidus temperature has just been given. The specific volume at the solidus temperature is determined by the specific volume at room temperature and the cubical contraction in the solid state.

12. Cubical contraction is three times the linear contraction. The linear contraction of any cast iron may be determined conveniently by casting in sand a bar of the design shown in Fig. 4. A pattern of this shape has an advantage over the form ordinarily used in that rapping is not required in removing it from the sand. The difference in the dimension *A-B* of the pattern

and the corresponding dimension of the casting is the linear contraction per foot of the metal.

13. The specific volumes at room temperature (25 degs. Cent. or 77 degs. Fahr.) of the 12 melts of cast iron were determined experimentally and are plotted against the per cent of total impurities in Fig. 5. The specific volume at room temperature of any cast iron whose amount of total impurities lies within these limits can be obtained from this curve.

III—APPLICATION OF METHOD

14. An example of the application of the above method for the determination of the total shrinkage undergone during casting by an iron of the following composition, whose linear contraction has been determined to be 0.12 inch per foot, is:

Total carbon, per cent.....	3.25
Silicon, per cent.....	2.00
Manganese, per cent.....	0.50
Phosphorus, per cent.....	0.70
Sulphur, per cent.....	0.05

“Total impurities,” per cent.. 6.50

15. The specific volume of this iron, having total impurities of 6.5 per cent, can be determined for any temperature in the liquid state from Fig. 2. For 1450 degs. Cent. (2642 degs. Fahr.), for example, a straight line passed through the points corresponding to 1450 degs. Cent. and 6.5 per cent impurities, respectively, intersects the third or specific volume scale at 0.1488. The specific volume of this iron at 1450 degs. Cent. (2642 degs. Fahr.) is, therefore, 0.1488 cu. cm. per gram.

16. Likewise, the specific volume of this iron at 1350 degs. Cent. (2462 degs. Fahr.) will be found to be 0.1471 cu. cm. per gram; and at 1250 degs. Cent. (2282 degs. Fahr.), 0.1454 cu. cm. per gram. These values correspond to the points *A*, *A'*, and *A''* in the curve of Fig. 6.

17. According to Fig. 3, the liquidus temperature for an iron containing 6.5 per cent total impurities is 1210 degs. Cent. (2210 degs. Fahr.)—point *B*, Fig. 6. The specific volume corresponding to this temperature is 0.1447 cu. cm. per gram. The portion *A-B* of this curve (Fig. 6) represents the change in specific volume (contraction) of the liquid metal on cooling from 1450 degs. Cent. (2642 degs. Fahr.) to 1210 degs. Cent. (2210 degs. Fahr.), the beginning of solidification. This amounts to

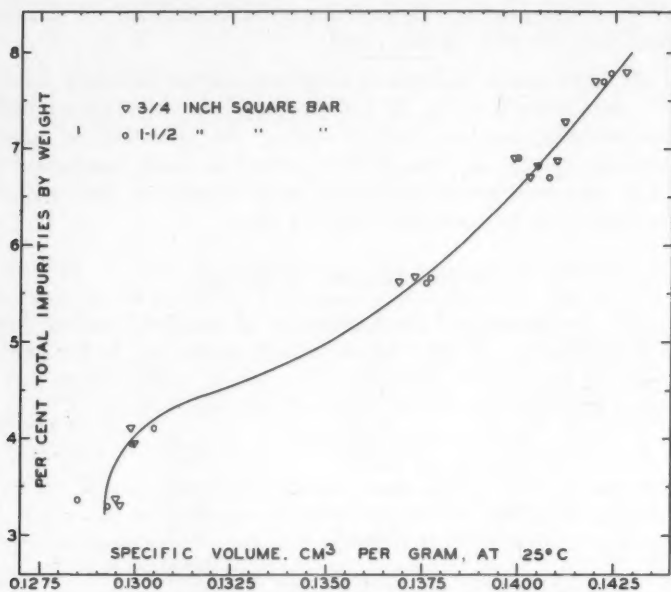


FIG. 5—RELATION BETWEEN SPECIFIC VOLUME OF CAST IRON AT ROOM TEMPERATURE AND TOTAL IMPURITIES.

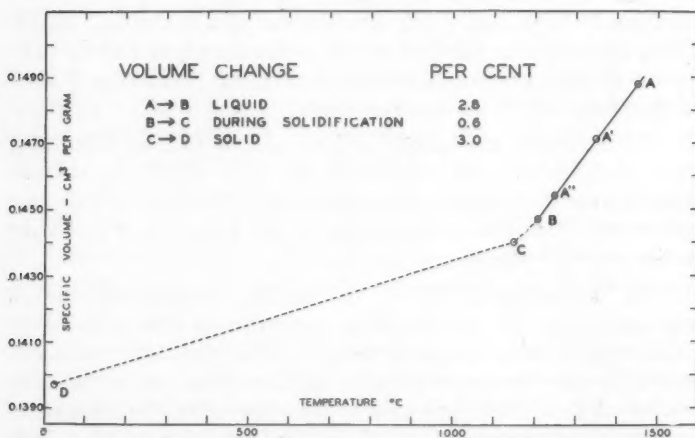


FIG. 6—VOLUME CHANGES OCCURRING IN A TYPICAL GRAY CAST IRON AS DETERMINED BY THE METHOD DESCRIBED IN ACCOMPANYING PAPER.

$$2.8 \text{ per cent } \left(\frac{0.1488 - 0.1447}{0.1488} \times 100 = 2.8 \text{ per cent} \right)$$

18. The change in specific volume (contraction) from 1150 degs. Cent. (2102 degs. Fahr.), end of solidification, to room temperature is determined as follows: According to Fig. 5, the specific volume at room temperature of an iron containing 6.5 per cent impurities is 0.1397 cu. cm. per gram (point *D*, Fig. 6).

19. The specific volume of the solid metal at 1150 degs. Cent. (2102 degs. Fahr.) is calculated from the linear shrinkage, which, for this iron, was found to be 0.12 inch per foot, or 1 per cent. Therefore, the cubical contraction is 3 per cent. The specific volume of the iron at room temperature is, therefore, 97 per cent (100 — 3) of the specific volume at 1150 degs. Cent. (2102 degs. Fahr.) Hence, the specific volume at 1150 degs. Cent. is $0.1397 \div 97$, or 0.1440 cu. cm. per gram (point *C*, Fig. 6).

20. The shrinkage during solidification is numerically equal to the difference between the specific volume of the liquid iron at 1210 degs. Cent. (2210 degs. Fahr.)—0.1447 cu. cm. per gram—and the specific volume of the solid iron at 1150 degs. Cent. (2102 degs. Fahr.)—0.1440 cu. cm. per gram. This amounts to 0.6 per cent $\left(\frac{0.1447 - 0.1440}{0.1447} \times 100 = 0.6 \text{ per cent} \right)$

IV—SUMMARY

21. The method for rapidly determining the volume changes occurring in cast iron during casting, as described in this paper, is an indirect one based upon a compilation of experimental data from 12 melts of cast iron varying in composition from gray to white cast iron. Application of this method requires a knowledge only of composition and linear contraction after solidification.

22. The volume changes occurring in a typical gray cast iron as determined by this method are as follows:

(a) Shrinkage of the liquid metal (1450 degs. Cent. to 1210 degs. Cent.—2642 to 2210 degs. Fahr.), 2.8 per cent.

(b) Shrinkage during solidification (1210 degs. Cent. to 1150 degs. Cent.—2210 to 2102 degs. Fahr.), 0.6 per cent.

(c) Shrinkage in the solid state (1150 degs. Cent. to 25 degs. Cent.—2102 to 77 degs. Fahr.), 3.0 per cent.

DISCUSSION

ORAL DISCUSSION

MEMBER: Will the author tell us the range of total impurities of irons studied?

C. M. SAEGER, JR.: The irons studied ranged in composition from white to gray iron, having total impurity contents of about 3.5 to 7.5 per cent, respectively. As stated earlier, the exact compositions of the 12 irons investigated will be published in the Bureau of Standards *Journal of Research*, May 1932, and also will appear in the American Foundrymen's Association TRANSACTIONS.*

MEMBER: Did the authors consider nickel, chromium and molybdenum as impurities in that set-up?

C. M. SAEGER, JR.: No, they were not considered in this investigation. We have studied only irons containing carbon, silicon, phosphorus, manganese and sulphur.

H. A. SCHWARTZ:¹ The writer has had some opportunity to follow the work of Mr. Ash while it was progressing at the Bureau. During the progress of the experiments he was impressed with the importance of the project, and it is a pleasure to welcome the present publication which makes an attempt to render the data useful to the foundry without the necessity of repeating heat for heat the somewhat refined measurements upon which the present paper is based.

The authors have deliberately confined their discussion to the determination of the volume change on freezing, and the reader no doubt understands that this is not the only variable of importance in considering the likelihood of shrinkage voids in actual castings. In their attempts to render the results available to foundrymen without further experimentation beyond the determination of linear shrinkage and chemical composition, it is feared that the authors have generalized too far and that the user of their method may fall into grievous error unless he understands clearly the limitations within which the method applies.

The authors' entire discussion assumes that the effect upon specific volume in the liquid state and solid state and upon the liquidus temperature, is the same for all elements. If their concentrations are expressed in weight per cent, this is certainly not to be assumed *a priori*, and in the present writer's opinion the assumption is justified only within small ranges of composition.

He has no available data which might be used to check the authors' conclusions with regard to density in the liquid state. When, however, the authors in their Fig. 3 show a relation between the liquidus temperature and the per cent of the impurities, summing for this purpose all the elements which are not iron, they have certainly contradicted what we already know of many equilibrium diagrams.

* See page 188 of the present publication.

¹ Manager of Research, National Malleable & Steel Castings Co., Cleveland.

The slope of the liquidus line in the iron-carbon diagram, the iron-silicon diagram, the iron-phosphorus diagram, the iron-sulphur diagram and the iron-manganese diagram, is by no means the same. This fact can be checked readily by the reader if he will examine the published binary equilibrium diagrams.

Raoult's law would make it probable that if the concentrations were expressed as a mol fraction instead of as a weight per cent, the effect of equal concentrations of the several elements might be somewhat nearly equal; even this is not true with precision.

Having in mind the still greater complexity of the ternary, quaternary and even more complex systems which will be found in cast irons, such a generalization as the authors have made must be very strictly limited to the range of alloys with which they worked, and not rashly extended to alloys similar to others in total content of impurities but in which the distribution of impurities might be widely different. Indeed, in Fig. 3 it appears that a liquidus temperature of just under 1150 degs. Cent. (2102 degs. Fahr.) was observed by the authors over a range of impurities from somewhat under 7 per cent to somewhat under 8 per cent, so that

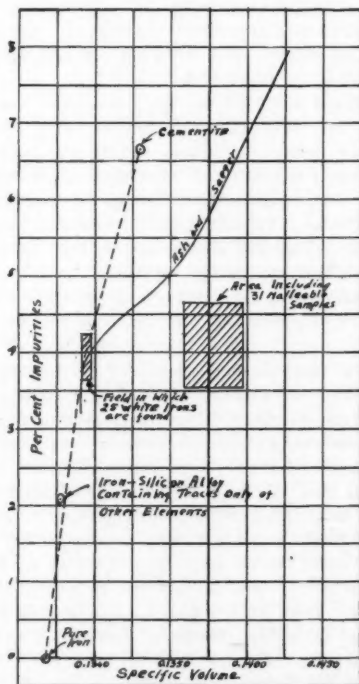


FIG. 7.

within their own range of composition the amount of impurities required to depress the liquidus of pure iron to 1150 degs. Cent. (2102 degs. Fahr.) is indeterminate within 1 per cent, *i. e.* within more than one-eighth of the total impurities present, depending upon what the particular impurities are.

A similar criticism must be made of the authors' Fig. 5, which is expected to permit of the computation of the specific volume at room temperature from the chemical composition. In this the authors have taken no account of the fact that carbon may be present as either graphite or cementite with widely different effect upon the density, and apparently they have tacitly assumed that the particular degree of graphitization encountered in their test specimens will be reproduced in all castings irrespective of size, cooling rate and so on, and, moreover, irrespective of the distribution of their several elements within the total content of impurities.

In the diagram herewith (Fig. 7) the writer has reproduced the Ash and Saeger curve and has plotted in addition the area in which the observed densities of 25 white cast irons examined in this laboratory fell. The location of this area on the lower rapidly curving portion of Ash and Saeger's curve constitutes an excellent confirmation of the observations. There is plotted also the specific volume of pure iron, the specific volume of a pure iron-silicon alloy examined in this laboratory, and the accepted specific volume of cementite.

It will be observed that neither the cementite, nor the iron-silicon alloy, nor the pure iron, fall upon the authors' curve or upon that curve when prolonged. The dotted line which the present writer has drawn in his own diagram should represent at least a rough approach of the effect of total impurities upon specific volume when these impurities consist of only silicon and carbon. The approximate straightness of this line suggests that combined carbon and silicon are at least approximately interchangeable in their effect on specific volume.

The authors' curve, diverging sharply to the right after it leaves the white iron field, is an expression of the particular degree of graphitization which they encountered.

The writer has plotted also a rectangular area enclosing the composition and density ranges of a series of malleable iron here examined, in which the carbon is substantially all in the temper or graphite form. The shift in specific volume, and the greatly increased range of specific volumes, is quite noteworthy.

It would appear that the user of Ash and Saeger's method would be well advised either to make density determinations at room temperature, or at any rate to include the graphite determination in his chemical analysis, using the latter as an important criterion of the density to be expected. If he will apply this precaution, he can apply the method to the particular cooling rates with which he has to deal without falling in error in his opinion as to the change of volume during freezing of the metal with which he is working.

It may be suggested that for the authors' purpose of determining the volume change during freezing, the alignment chart of Fig. 2 and the

graphic determination of the liquidus temperature from Fig. 3 could be combined by superimposing on the temperature scale of Fig. 2 an additional scale of per cent total impurities. If we consider the authors' conclusion that the liquidus temperature is a straight-line function of per cent total impurities to be justified, then an equal-divided scale for total impurities would result; and, by using this scale, the solution for the specific volume at the solidus can be obtained in a single operation. If the coefficient of expansion of the liquid is desired, then Fig. 2 still could be used in its present form.

The writer has no doubt that these several facts are all clearly understood by the authors of the paper, but he regrets greatly that they did not sufficiently enlarge their discussion so as to make plain to the hasty reader what the limitations are within which their data are applicable.

REPLY BY AUTHORS

C. M. SAEGER, JR.: The authors appreciate the discussion by Mr. Schwartz. The object of submitting this paper was not only to give a summary of the shrinkage characteristics of a series of commercial cast iron (see footnote 3) but also to give the foundrymen a short-cut method for readily determining the volume changes of a cast iron during cooling from the liquid state to room temperature.

As inferred by its title, the method does not lend itself to a high degree of precision. The relations pointed out are true when applied to cast irons whose compositions fall within the range of those irons upon which the data are based. The irons studied are representative of commercial types of cast iron, but no pretense is made to apply the method to unusual compositions or to specially alloyed cast irons.

Although the authors agree with several of the points mentioned by Mr. Schwartz, his comments appear to give little consideration to the intended purpose of the method as stated in the previous paragraph. For this reason, no attempt will be made to reply in detail to the criticism, as such would add little value to the paper.

Some of the comment is considered rather outside the subject matter of the paper. The authors cite the comment in regard to the specific volume of malleable iron. Since malleable iron is a heat-treated cast iron, it really finds no application in this method.

Figure 5 refers only to the specific volume-temperature relations of cast materials, and these of a specified cross-section. The validity of

this relation is strengthened by Mr. Schwartz' experimental values for the specific volume of white cast iron coinciding with the results obtained by the authors.

For a more precise method for determining volume changes of cast iron, publications mentioned at the beginning of the paper should be consulted (see footnotes 2 and 3).

A Method for Study of Shrinkage and Its Distribution In Castings

By N. B. PILLING* AND T. E. KIHLGREN,* BAYONNE, N. J.

Abstract

A refinement in the method of using an unfed test casting is developed which yields, in a simple operation adaptable to the foundry, quantitative measurement of specific weight at the freezing point, linear shrinkage, and freezing (or solidification) shrinkage. The shrinkage constants of a number of bronze and nickel casting alloys are given. Another method also is described for revealing the existence and distribution of capillary shrinkages in a sectioned casting, which involves a procedure for charging the voids with a reactive fluid and expelling it against a sheet of sensitized paper.

1. The importance of the volume changes suffered by cast metals in freezing and during subsequent cooling to the ordinary temperature, is too obvious to require defense for its study. In addition to the purely geometrical problem which is presented, the shrinkage characteristics of alloys determine to a considerable degree the ease with which sound and useful castings may be produced.

2. Alloys as well as simple metals differ greatly among themselves, both as to the extent of the dimensional change by which the size of a casting differs from that of the pattern from which it is produced, and as to the tendency to concentrate or to disperse the "pipe" formed as the result of the change in density during freezing. Consideration of these points has engaged the attention of foundrymen and metallurgists for many years, but in this short paper a review of these important contributions and the significance of shrinkage will be passed lightly

* International Nickel Co.

NOTE: This paper was presented and discussed before one of the nonferrous sessions at the 1932 convention of the American Foundrymen's Association.

by in order to describe a method whereby these shrinkage properties can be dissected and laid bare for study in a simple way.

MEASUREMENT OF SHRINKAGE

3. A number of means, some quite laborious, are available for measuring the shrinkage of metals. A recent and readily available publication¹ gives an adequate and critical review of these methods, and further discussion of them will not be undertaken.

Method of Unfed Casting

4. The method which has been developed is not novel in conception, but consists of a refinement in the scheme of studying an unfed casting. It appears that previous effort in this direction has consisted largely in comparisons of the weights of fed and unfed castings, and Saeger and Ash, in appraising the method, state:

"These methods . . . undoubtedly gave useful results to the foundry in which they were used. However, there is no means of differentiating between the shrinkage of the liquid metal and that occurring during solidification. Furthermore, since feeding occurs during the entire pouring period, it is difficult to determine just what was measured by the foregoing methods."

5. These difficulties are not inseparable from this method of attack. Assuming that the significant shrinkage constants are (1) the volume change encountered in passing from the liquid to the solid state, and (2) the extent of the discrepancy between pattern and casting dimensions, it appears that both can be measured in a single operation involving slight manipulative skill and hence suitable for the foundry floor. The requirements seem to be as follows:

- (a) A mold of known and reproducible volume and simple geometrical shape.
- (b) Adequate venting and an effectively choked gate.
- (c) Casting at the freezing point of the alloy.

¹"A Method for Determining the Volume Changes Occurring in Metals During Casting," C. M. Saeger, Jr. and E. J. Ash, *Bur. Stds. Int. Research*, vol. 8, p. 37, 1932.

6. With this set-up, and from other information obtainable directly from the casting produced, both shrinkage constants can be derived.

7. If the melt is cast at the freezing point to eliminate liquid shrinkage, and if

V = Mold volume,

V' = Volume of metal at room temperature, exclusive of all voids,

v = Total shrinkage in volume to room temperature,

w = Weight of unfed casting, and

d = Density of metal at room temperature,

then: $v = V - V'$

$$V' = \frac{w}{d}$$

therefore: $v = V - \frac{w}{d}$

$$\text{and } \frac{v}{V} = 1 - \frac{w}{Vd}$$

The total shrinkage coefficient, or per cent decrease in volume to room temperature, in terms of the liquid volume at the commencement of freezing, is

$$S = 100 \frac{v}{V} = 100 \left(1 - \frac{w}{Vd} \right)$$

8. The volume change computed obviously includes the volume of the pipe (whether concentrated or dispersed) plus the volume change due to thermal contraction of the solid metal. The linear shrinkage can be determined directly from gage marks on the casting, and if expressed as a percentage the corresponding volumetric shrinkage is simply three times this value. The freezing shrinkage is then taken by difference. The measurement of this quantity thus requires only four things (1) the volume of the mold cavity, (2) the density of the sound alloy, (3) its linear shrinkage, and (4) the weight of the unfed casting.

Design of Test Specimen

9. A pattern design to accomplish this is shown in Fig. 1. It consists of a cylinder, axis horizontal, fed from below through a generous sprue and a thin gate. The cylindrical surfaces are

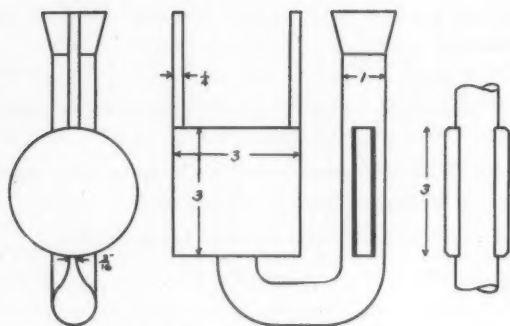


FIG. 1—SHRINKAGE TEST SPECIMEN.



FIG. 2—SHRINKAGE TEST CASTING.

touched at the crown by two vents, heavy to permit the rapid clearance of air. Gage marks for the estimation of linear shrinkage need to be on a completely fed portion; a pair of ribs on the side of the sprue, symmetrically arranged to assure freedom from warping during cooling, serve this purpose well.

10. In operation, the pattern is molded with a vertical parting line in core sand with a linseed-oil binder, and baked hard. The lengths of the gage marks vary somewhat from mold to mold and are each measured with a micrometer to 0.001 inch before assembly. The fluid metal is allowed to cool to the freezing point and then is quickly cast into the mold.

Table 1

Weight, gm.	2922
Density, in. per cc.	8.89
Mold Volume, cc.	368
Gage Lengths:	*
Mold, in.	3.052
Metal, in.	2.981
Specific Weight, lbs. per sq. in.	0.285
Total Volumetric Shrinkage, %	10.7
Linear Shrinkage, %	2.32
Solid Volumetric Shrinkage, %	6.9
Freezing Shrinkage, %	3.8

11. This regulation of the metal temperature is critically important but is not particularly difficult and does not require the measurement of temperature. With an Ajax high-frequency furnace, the exposed surface of the cooling melt can be watched until it crusts over slightly; power then is reapplied and held for a moment or two after the disappearance of the last fleck of solid crust.

12. With crucible melts, the pot is pulled and allowed to cool on the floor until rubbing with a graphite rod first detects a roughening of the inside crucible walls. Properly executed, the mold fills completely and the two vents fill about half way (Fig. 2). The massiveness of the cylinder in comparison with the gate and vent sections insures an absence of feeding effects.

13. The density of the metal free of voids is conveniently obtained from a portion of the vent riser, after first consolidating the sample by a light hammering. The specimen weight is taken after trimming off the gate and risers, the symmetrical shape of the cylinder assisting in this.

14. As an example, Table 1 shows the method of computation, taken from an experiment in copper.

Calibration

15. The volume of the cylindrical portion of the mold is measured dealing with the two halves separately. The gate is stopped off with plaster and a plate of glass cemented on to the

Table 2

COMPARISON OF METHODS

Metal.	Freezing Shrinkage, % Vol. of Liquid at Freezing Point		
	Present Method.	Other Methods.	Authority.
Aluminum	6.8	7.1	Edwards & Moorman ¹
		6.5	Saeger & Ash ²
Magnesium	3.8	4.5	Edwards & Taylor ³
Tin	3.0	2.9	Saeger & Ash ²
Lead	3.1	3.1	Saeger & Ash ²
		2.9	Harris ⁴
Copper (deox.)	3.8	4.1	Borneman & Sauerwald ⁵
85-5-5-5	6.3	5.0	Saeger & Ash ²

¹ *Chem. Met. Engr.*, vol. 24, no. 61, 1921.

² *Bur. Stds. Jnl. Research*, vol. 8, no. 37, 1932.

³ *Transactions A. I. M. E.*, vol. 69, no. 1070, 1923.

⁴ *National Metals Handbook*, 1930, p. 709.

⁵ *Zs. Metallkunde*, vol. 14, no. 254, 1922.

parting surface. The half-mold then is filled with mercury to the vent level and its weight determined. Repeated impressions of the pattern, after baking in a core oven, gave a sufficiently close reproducibility in volume to establish this constant once and for all, as follows:

Left Half.	Right Half.	Total, Avg.
182.7 cc.	185.1 cc.	
183.1	185.2	
183.	185.1	
183.2	185.2	368.2 cc.

16. The freezing shrinkage of several metals has been carefully measured by other investigators using refined methods allowing greater physical precision and involving determinations of the specific volume of the metal for both solid and liquid states at the freezing point. As a check upon the adequacy of the present method, a comparison is given in Table 2 for several metals for which this constant is known.

Table 3
SHRINKAGE CONSTANTS OF SEVERAL CASTING ALLOYS

Name	Type Composition	Specific Weight of Liquid at Freezing Point, lbs. per cu. in.	Total Volumetric Shrinkage, %	Linear Shrinkage, %	Freezing Shrinkage, %
Copper	Deoxidised	0.285	10.7	2.32	3.8
Red Brass	Cu 85, Zn 5, Pb 5, Sn 5	0.287	10.6	1.44	6.3
Yellow Brass	Cu 70, Zn 27, Pb 2, Sn 1	0.271	12.4	1.98	6.4
Bearing Bronze	Cu 80, Sn 10, Pb 10	0.293	11.2	1.29	7.3
Manganese Bronze	Cu 56½, Zn 40, Fe 1¼, Sn ½, Al 1, Mn ½	0.261	11.5	2.32	4.6
Aluminum Bronze	Cu 90, Al 10	0.241	11.2	2.37	4.1
Aluminum	Commercial	0.086	12.2	1.79	6.8
Nickel	Ni 98, Si 1.5, C 0.1	0.271	14.2	2.70	6.1
Monel Metal	Ni 67, Cu 32	0.272	13.9	2.53	6.3
Everbrite	Ni 30, Cu 62, Fe 7	0.276	13.0	2.18	6.5
Nickel Silver	Ni 20, Zn 15, Cu 65	0.279	12.1	2.19	5.5
Carbon Steel	C 0.25, Si 0.2, Mn 0.6	0.250	11.4	2.52	3.8
Ni-Resist	Ni 13, Cu 7, Cr 2, C 3, Fe bal.	0.248	7.8	2.07	1.6

Shrinkage Constants of Some Metals and Alloys

17. As a matter of interest, Table 3 gives the shrinkage constants of a number of familiar casting alloys and demonstrates the diversity in range of melting points which this method of measurement finds feasible.

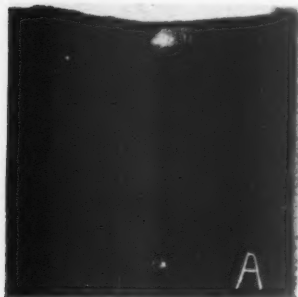
SHRINKAGE DISTRIBUTION

18. It is obvious that the manner in which the shrinkage cavity distributes itself is quite as important a casting property as the magnitude of the shrinkage itself. The simple metals tend to concentrate this void in a single central pipe, a characteristic also shown by many "high shrinkage" alloys. On the other hand,

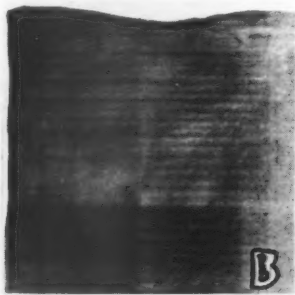
some alloys so completely disperse this pipe as to leave little trace of it evident on sectioning.

19. These characteristics are revealed in some detail by splitting open the unfed cylinder described in the preceding section. It is quite beyond the intent of this paper to discuss the significance or cause of differences in shrinkage distribution, and it suffices for the present to show Fig. 3. This illustrates the point that a high-freezing shrinkage does not necessarily indicate a strong tendency to form a pipe.

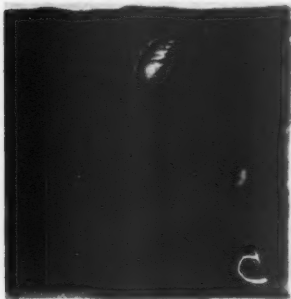
20. These coarse differences in distribution of shrinkage extend to a much finer scale, and while evidence regarding them



A: RED BRASS (85-5-5-5), FREEZING SHRINKAGE 6.3 PER CENT.



B: BEARING BRONZE (80-10-10), FREEZING SHRINKAGE 7.3 PER CENT.



C: ALUMINUM BRONZE (90-10), FREEZING SHRINKAGE 4.1 PER CENT.



D: NICKEL SILVER (65-20-15), FREEZING SHRINKAGE 5.5 PER CENT.

FIG. 3—DISTRIBUTION OF SHRINKAGE PIPE IN UNFED CYLINDERS POURED AT FREEZING POINT.

appears in fracture and fluid pressure tests, their existence and arrangement can be shown more positively in another kind of test about to be described.

Contact Print Method

21. A chance observation that etched surfaces of bronze castings frequently exude copper salts to different degrees after standing for some length of time, led to the development of a method in which dendritic shrinkages and other capillary voids can be charged with a reactive fluid which is expelled upon a sensitized paper surface to form a permanent record. However, its successful application depends upon carefully controlling certain steps in the operation, which therefore needs description in some detail.

22. The casting to be examined is cut to form a slice about 1/4 in. thick, one of the surfaces exposed being that selected for examination. The test surface is ground approximately flat, either mechanically or upon a belt grinder.

23. At this stage many of the smaller voids are sealed over by the flow of metal and are re-exposed by a slight etch in an active solvent. For bronzes, a 30 per cent nitric acid solution has been found suitable, and for other materials an equivalently vigorous etchant is desirable.

24. The degree of etch is not particularly important, but in general is an amount barely sufficient to reveal the macrostructure. Over-etching opens up the capillary fissures to an extent which interferes with the test, and "deep etching" is inadmissible.

25. The etched specimen then is boiled to free it completely from acid, and is thoroughly dried in a chemist's air oven at about 230 degs. Fahr. After cooling to room temperature, the capillary voids communicating with the surface are clean, dry and empty, and ready to receive the reactant. This consists of a saturated water solution of ferrous sulphate, or ferrous ammonium sulphate. The specimen is immersed face up and let soak for a few minutes.

26. The cleansing operation which follows is perhaps the most critical step in the process. A stream of rinsing water is provided, its temperature being the same as that of the ferrous

sulphate solution (this is easily arranged with an ordinary mixing faucet). In this stream the specimen is thoroughly washed and wiped dry with a towel. Should the rinse be colder than the test specimen, the reactant fluid will be diluted by further ingress of water; should it be warmer, some of the reactant will be expelled and lost.

27. At this stage the specimen stands charged with reactant and ready for the transfer. The transfer paper is a fine-grained stock coated on one side with potassium ferrieyanide; a suitable grade of paper is commercially available, coming in size up to 22 x 17 in.

28. If the transfer is made directly to the dry paper, the spot formed is about the same size as the fissure on the specimen, and the pattern remains too fine grained for visual examination. A more useful departure is to enlarge preferentially the imprint of the reactant, and this can be done readily by dampening the paper so that the tiny drop spreads out instead of being quickly absorbed.

29. This is conveniently done by storing the paper supply in a humidor, but since the amount of spread is rather sensitive to the presence of moisture on the surface, a further conditioning of the paper is given just before making the transfer. This consists in pressing (for a few minutes) the limp sheet as taken from the humidor between two thicknesses of blotting paper, the bottom one saturated with water, the top one (in contact with the sensitized surface) dry.

30. Both paper and specimen are now ready for contact. The sheet is laid on a resilient layer of damp blotting paper, which in turn rests on a flat surface, and the specimen laid face down upon it. It then is pressed firmly down (about 5 lbs. per sq. in.) and gently warmed. This expands the air spaces behind the enclosures of reactant and expels it in tiny drops, in amount proportioned to size of void, to react with the sensitized surface.

31. A convenient way of applying heat and pressure simultaneously is to provide a second slice from the casting being examined, heating this in an air oven to about 230 degs. Fahr. and interposing it between the specimen and the weight; more simply, the weight itself may be a block of copper.

32. The pattern which is developed corresponds in detail

of arrangement with that of the shrinkage and other voids of capillary magnitude existing in the casting, yet enlarged sufficiently for emphasis. Gas holes and other voids of greater than capillary dimensions do not register in this form of test, since the reactant fluid is washed from them in the rinsing step. For this reason, these coarser defects do not interfere with the searching and delicate inspection of adjacent areas.

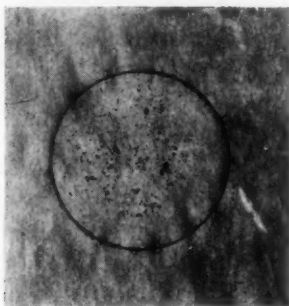


FIG. 4—SHRINKAGE DISTRIBUTION IN SAND-CAST BRONZE CYLINDER.

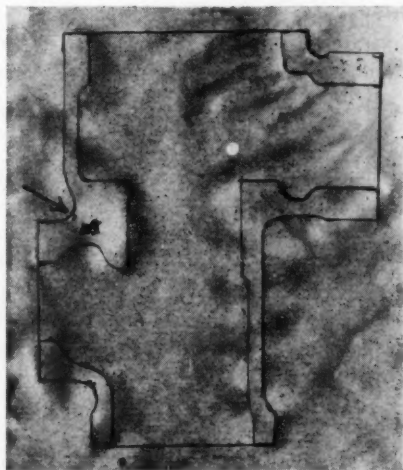


FIG. 5—NICKEL SILVER VALVE BODY. ARROW INDICATES LOCATION OF LEAK DETECTED IN PRESSURE TEST.

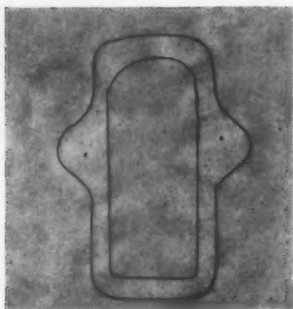


FIG. 6—PRESSURE CASTING, SHOWING CONCEALED SHRINKAGES WITHIN HEAVY SECTIONS.

33. With the exception of the rinse, none of the steps need close control, yet it is a great aid to reproducibility if a definitely timed sequence is laid out and followed.

34. Several examples of contact print obtained by this method are shown in Figs. 4, 5 and 6. The first of these is a section cut from a solid cylinder cast in bronze in green sand. It serves well to show the almost complete soundness of the chill in contrast with the central portions, and to illustrate the varying response of differently sized pores.

35. Fig. 5 is a sectioned nickel-silver valve body, the plane of the section passing through a slight leak detected in a water pressure test. The shrink responsible for this is clearly revealed.

36. Fig. 6 is a sectioned nonferrous pressure casting in which hidden shrinks are detected in the pair of thickened lobes.

37. Since complicated shapes can be examined with the same ease as simpler ones, this method of examination can be applied not only to the study of the shrinkage properties of alloys but also to the perfection of casting design as well. While a technique suited particularly to copper casting alloys has been described, a selection of reactant and sensitized paper for other materials can be made. The necessary condition, of course, is that the reactant fluid be unaffected by the metal in question.

(Discussion begins on next page)

DISCUSSION

ORAL DISCUSSION

G. H. CLAMER:¹ Do the figures in Table 1 on shrinkage check with those from the Bureau of Standards method? Secondly, were the locations of the holes in the different metals always characteristic of that particular method?

I recall a paper some years ago in which the author described some tests made in a similar way, using paraffine. There seemed to be no regularity as to where the holes occurred; they occurred almost anywhere in the casting, on a straight cylindrical piece such as the authors have shown here. Of course, there is no difference in cross-section as to the particular location of the holes, and I wonder if enough of the castings were cross-sectioned to permit determining whether the holes for a particular metal always occurred in a particular place in the castings examined.

N. B. PILLING: As to the first question, on whether this method of measuring shrinkage checks with that of the Bureau of Standards, several of the comparison figures in Table 1 were from that source and show satisfactory agreement. The discrepancy in the case of 85-5-5-5 mixture has its source in the way the linear shrinkage is separated from the freezing shrinkage; the total shrinkage in both instances is quite similar.

High-lead and low-lead copper alloys have a fairly similar total shrinkage, but the linear shrinkage of the high-lead alloys is quite low, accounting for the higher freezing shrinkage noted. This illustrates the point that freezing shrinkage and linear shrinkage intermesh to an extent which makes their separation difficult in some cases.

As to the characteristic nature of the capillary shrinkages, we have found that different alloys differ in their tendencies to form those capillary voids. Repeated impressions can be taken from the same section which check; the difficult thing is to get exactly the same spread on each drop each time, although patterns can be obtained which are recognizable duplicates. Again, as to their distribution, we usually have found that chills are free from them and the centers of heavy sections often full of them.

CHAIRMAN SAM TOUR:² This method of shrinkage determination certainly is simple enough for all foundries to use. I wonder what practical application can be made of the information to the advancement of our foundry practice.

It is rather surprising that the liquid shrinkage found on some of the mixtures we have always considered "bad actors" is not as large as on some of the "good actors" in the foundry. Is this true or is it in the nature of the test described? The authors' logic seems to be satisfac-

¹ President, Ajax Metal Co., Philadelphia.

² Vice-President, Lucius Pitkin, Inc., New York.

tory, yet if their figures are correct it looks as though we should be able to do a better job on some of these alloys.

N. B. PILLING: The answer is, perhaps, that the magnitude of the freezing shrinkage is not as dominating a factor as has been supposed, and that a more important consideration is the habit of concentrating this shrinkage in an enclosed pipe or of transferring it to the outside of the casting through collapse of the freezing shell. These two habits seem to be related to the freezing range, the first mode of distribution being associated with metals or alloys having a sharp freezing point, like copper or aluminum bronze, the second with those showing a long freezing range. The sections of unfed castings shown do not represent, of course, what would occur with a casting thoroughly and generously supplied with risers.

MEMBER: Did the authors make any attempt to pour their metal from the top? From the practical foundry standpoint, the specimen of Fig. 2 gives us a perfectly solid gate and runoff, but if a foundryman is looking for any shrinkage at all he naturally would find it in the casting the minute it was poured. My idea would be that perhaps one could get a better specimen by pouring from the top with a long, narrow, thin gate. This would do away with any shrinkage except bottom shrinkage, as a result of the last metal going in being hotter.

N. B. PILLING: We tried gating the specimen in various ways and did not find that the location of the gate was particularly important in preventing feeding of the cylinder from the sprue.

MEMBER: I do not think a true specimen can be obtained that way. One could put on a gate, however, although that would not cause any feeding.

N. B. PILLING: Of course, we are deliberately trying to emphasize shrinkage as much as possible, not to prevent it.

E. R. DAREY:² How are we to differentiate between a shrinkage cavity and a possible gas cavity? We may call a gas cavity a shrinkage cavity, in which case we would be measuring a shrinkage that would be abnormal to the material as we are handling it, probably to the manner of melting or to cores or something of that nature.

N. B. PILLING: It is natural to wonder how a gas hole will affect this method. The quantities requiring measurement do not depend on whether any gas comes out or not, provided the melt is not bubbling when it is poured and that the mold is originally completely filled with liquid metal.

If gas comes off after the metal has filled the mold, it simply expands into the shrinkage cavity; if the amount released is so great that it exerts pressure on the shrinkage cavity, there may be distension of the specimen but that does not change the weight. However, we never have had a case where the gas discharge was great enough to cause distension.

² Chief Metallurgist, Federal Mogul Corp., Detroit.

In short, a moderate gas release might change the distribution but not the magnitude of the freezing shrinkage.

CHAIRMAN SAM TOUR: Mr. Pilling mentioned one thing that might be stressed somewhat. The apparent shrinkage figure is not the all-important figure in foundry practice. The important item is: Where is the particular shrinkage going to be in the final product? In other words, can the shrinkage be put out of the casting?

The authors interpret this in terms of freezing range. I believe that interpretation is open to some question; that it is possibly the question of fluidity of the metal before freezing, rather than the freezing range. I can conceive that a metal with small freezing range, but which is thoroughly fluid, will feed much better than a metal with a wide freezing range and which is quite mushy and thick in the freezing range. We might prefer a metal which is very fluid down to the freezing range and which would run in and fill up the shrinks and thereby drag the shrink into the gate.

E. R. DARBY: Consider, for example, an aluminum bronze, which has been mentioned. Its temperature freezing range is very slight, yet it is one of the worst actors we have, liable to leave the very holes to which reference has been made.

CHAIRMAN SAM TOUR: The authors brought out that aluminum bronze has very low shrinkage; it is very fluid when molten.

E. R. DARBY: My remark was in connection with the chairman's statement that the long temperature freezing range metal would be one of the worst actors, but my point is that aluminum bronze, which has practically no temperature freezing range, is one of the worst actors in the foundry.

R. L. BINNEY: Looking forward to the application of this research to practice in the foundry, I wonder if the authors have investigated the various factors that might influence the results. The nature of the charge, the method of melting, and other conditions that vary in commercial practice before the metal is cast, might influence the constants he has determined. Were such items considered when these experimental heats were made, and are these figures applicable in all such cases investigated?

It is possible that the varying of the conditions I have just mentioned would have no effect on the freezing shrinkage, but it would be interesting to know definitely if they were taken into consideration. If all these phases of the problem have been investigated, it then would be possible to say that the factors determined by the authors would apply to an alloy under discussion regardless of the conditions of the charge or the type of melting. In other words, I would like to know if the factors determined are of such a nature that we may attempt to use them in practice without modification.

N. B. PILLING: I certainly would not say that this is the last word;

⁴Vice-President and Metallurgist, Binney Castings Co., Toledo, Ohio.

I would be disappointed if anyone got that impression. While an object of the paper is to describe a method of measuring the amount of freezing shrinkage in casting alloys, one result may be, as Mr. Tour aptly suggests, to show that this quantity is not, after all, the most important factor we think it is.

How Much Does It Cost To Train Foundry Apprentices?

BY J. FRANKLIN CARLZ,* OLEAN, N. Y.

Abstract

Believing that by training apprentices is the only way to get a sufficient supply of skilled foundrymen, with a flexible organization, less labor turnover, and to provide a training school for potential foremen, an apprentice course was established on a definite basis in 1927. The paper brings out the cost of training foundry apprentices, and detailed costs are given, the total cost per year per apprentice being given as \$176.54. The conclusion is reached that when comparing production cards with rates of pay and expenses of training on company time, the program is more than paying its way. Complete training schedules are listed.

INTRODUCTION

1. At Niagara some time ago, two business men were watching that tremendous water fall. One remarked to the other: "That is the greatest power in the world, and it is going to waste."

2. The second replied: "No, that is not the greatest power in the world. Man-power is greater than water-power, for man-power can harness water-power."

Man-Power Must Be Given More Thought

3. With this in mind, it is our opinion that greater attention must be given to the man-power item in business; and business, of

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course, includes foundry management. The human machine is vastly more important than mechanics, and since the road to business building lies in the direction of the development of manpower, it is advisable for foundry managers to keep in step.

4. What better way is there of doing this than to begin at the source? That is to say, when a young man enters your foundry as an apprentice, give him every advantage that will make him an excellent molder or core maker.

5. The most tangible advantage is a well-defined, systematized course in apprentice training that really functions. In the past, management often has been guilty of laying out an elaborate training program and then thinking that the job was done. For a course of this kind to be successful, interest must be constantly maintained. For any form of apprentice training to be really effective, it should be placed on an organized basis the same as any other department; and in many cases—perhaps all cases—it should be custom-made to fit the particular foundry that is going to use it.

6. The purpose of this paper is to bring out the cost of training foundry apprentices and in order that this may be clearly understood, a running description of our plan, along with itemized cost, perhaps would be of interest. Today, after five years of definitely planned training, our Apprentice Department is made up as follows:

Trade.	No. of Apprentices.
Machinists	32
Foundry	16
Pattern Maker	2
Draftsman	1
Electrician	1
	—
TOTAL	52

COST OF FOUNDRY LAYOUT

7. Previously we had trained foundry apprentices with more or less success using the old method. Before starting upon the new program (which we instituted in 1927), a study was made of our foundry to see if any additional layout was necessary for this new program.

8. The Clark Bros. Co. foundry, fortunately, is very well equipped. Not only have we the usual foundry equipment that goes with a foundry employing about 175 men, but in addition we have a modern sand-preparing installation, a Beardsley & Piper sandslinger, a Herman jarr rollover and pattern-drawing machine, and a small laboratory with various testing machines and instruments. Our survey showed that no added foundry equipment would be necessary.

9. Our superintendent and foremen had trained young men for many years in the various phases of apprenticeship and were well experienced to carry on under the new arrangement. We did not believe that special work and a special instructor were necessary, for what better training could a boy get than to be under first-line foremen, getting from them the benefits of their broad experience and knowledge?

10. We had found that the modern foreman, when approached correctly, was only too glad to give time and attention to young men serious in their endeavor to learn a trade. All of our foremen realized the value of a training program. Therefore, no added shop instructor was necessary to carry out the practical training of our young men. The foundry superintendent is in general charge of these boys and adheres to the very definite apprentice-work schedule sent him by the Apprentice Department, which will be briefly explained in connection with the cost of maintaining the schedule.

11. Because of these things, our plan required no expense in preparing our foundry for a modern apprentice course.

COST OF SCHOOL LAYOUT

12. After due thought and consideration, we decided to equip our own plant school. Since the company owned quite a few dwellings in the immediate vicinity of the plant, we chose the one that seemed best fitted to our plans for a school building, and bought for it the equipment shown in Table 1.

13. Figuring this equipment to last 20 years, the cost per year would be \$41.81; and, on the basis of 52 boys, the cost per apprentice per year would be \$0.81.

14. Some of this equipment was bought new and some of it slightly used. For instance, the blackboards were slightly used and were purchased from the city school system at a very low cost.

15. As for the building itself, all of the rooms listed in Table 1 are on the ground floor. The rooms in the upper story are used as storage and supply rooms. As an aid in developing neatness, orderliness, cleanliness, etc., in our apprentices, we keep our class rooms scrupulously clean. The walls and floors are painted yearly, and cheerful, bright coloring is used in maintaining them.

Table 1

COST OF APPRENTICE SCHOOL LAYOUT

Room No. 1—Drawing Room

No. of Items.	Items.	Cost.
12	Drawing tables with boards and T-squares	\$187.56
12	Stools	48.00
3	Wall blackboards	1.20
		<hr/> \$236.76

Room No. 2—Conference Room

12	Student arm chairs	\$ 99.00
12	Wall blackboards	4.80
1	Desk	15.00
1	Chair	4.00
		<hr/> \$122.80

Room No. 3—Library

1	Long table	\$ 35.00
8	Chairs	54.00
3	Open wall book-cases	7.50
1	Typewriter desk	37.60
1	Typewriter chair	14.00
1	Typewriter	106.50
		<hr/> \$254.60

Room No. 4—Office

1	Desk and chair	\$ 30.00
2	Chairs	8.00
1	Book-case	30.00
1	Drawing table	5.00
2	Filing cabinets	57.50
		<hr/> \$130.50

Miscellaneous

Electric-light equipment	\$ 23.49	
Linoleum	14.75	
Heating equipment, installation	22.80	
Other Expenses: telephone, curtain shades, etc.	30.50	\$ 91.54

GRAND TOTAL FOR SCHOOL LAYOUT..... \$836.20

CLARK BROS. CO.		FOUNDRY APPRENTICE												1931-1932
YEAR	NAME	NO.	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE
FIRST	TERIBURY	1	HELP MOLDER DRY SAND			HELP MOLDER GREEN SAND			CORE MAKING		SMALL		CORE MAKING	LARGE
	KELLEY	2	"	"	"	"	"	"	"	"	"	"	"	"
	DIFENTO	3	HELP MOLDER GREEN SAND			HELP MOLDER DRY SAND			CORE MAKING		LARGE		CORE MAKING	SMALL
	PATTERSON	4	"	"	"	"	"	"	"	"	"	"	"	"
SECOND	HARRIS	1			HOLDING	SMALL					HOLDING	MEDIUM		
	PALMER	2			"	"					"	"		
	FORABITO	3			"	"					"	"		
	SCHULTZ	4			"	"					"	"		
THIRD	SHIVER	1	CORE MAKING	SMALL		CORE MAKING	LARGE			TOP ROW SAND SMALL MEDIUM BOTTOM SAND	TOP ROW SAND SMALL MEDIUM BOTTOM SAND		BENCH	HOLDING
	LABOURI	2	"	"	"	"	"	"		TOP ROW SAND SMALL MEDIUM BOTTOM SAND	TOP ROW SAND SMALL MEDIUM BOTTOM SAND		"	"
	ANASTASIA	3	CORE MAKING	LARGE		CORE MAKING	SMALL		BENCH	HOLDING			PATTERN SAND SMALL MEDIUM BOTTOM SAND	TOP ROW SAND SMALL MEDIUM BOTTOM SAND
	BRENNAN	4	"	"	"	"	"	"	"	"	"		HOLDING	LARGE
FOURTH	HENDERSON	1	TOP ROW SAND SMALL MEDIUM BOTTOM SAND	HOLDING	MEDIUM		HOLDING	LARGE					HOLDING	LARGE
	OSTERMAN	2	TOP ROW SAND SMALL MEDIUM BOTTOM SAND	TOP ROW SAND SMALL MEDIUM BOTTOM SAND	TOP ROW SAND SMALL MEDIUM BOTTOM SAND		HOLDING	LARGE					HOLDING	LARGE
	BELVEES	3	HOLDING	MEDIUM	SMALL MEDIUM		HOLDING	LARGE					HOLDING	LARGE
	KELLER	4		HOLDING	MEDIUM			HOLDING	LARGE				HOLDING	LARGE

FIG. 1.—FOUR-YEAR SHOP SCHEDULE.

COST OF MAINTAINING WORK SCHEDULE

16. Before bringing out the cost of maintaining a work schedule, let us first see what constitutes our work schedule. Fig. 1 shows the work and time schedule used successfully at our plant. It may be explained as follows:

First Year Schedule

17. Starting with the first year, Boy No. 1 starts July 1, helping to make simple molds in dry sand. On October 1 he changes to the green-sand department, doing the same kind of work until January 1, at which time he progresses to the core-making department. Here he makes plain cores, first small and then large, until July 1, thus completing one year.

18. Boys Nos. 2, 3 and 4 do the same kinds of work during this first year, although the dates of change differ. The length of time put in at each department is the same, so that all four boys advance into their second year at the same time. It might be well to mention here that we make no distinction between molding and core-making apprentices; they both receive the same training.

Second Year Schedule

19. Proceeding now with the second year: Starting July 1, Boy No. 1 is given a floor of his own. He makes small molds until January 1, when he advances to medium-sized molds until July 1, completing another year. At this time, one-half of the apprentice period is now completed for all four boys who started out at the same time. They have had the same treatment and have had the same type of work.

Third Year Schedule

20. The third year is more varied, as will be noticed. Considering Boy No. 1, on July 1 he goes back to the core-making department, where he is instructed in the art of making complicated cores, working at it until January 1. On this date he is moved to the pattern shop for six weeks to learn something about patterns, their repair and care—until February 15. Then he comes back to the foundry for what the schedule refers to as "cupola practice," which is mostly work in our foundry labora-

tory. This period is of six weeks duration. On April 1 he proceeds to bench molding for three months, which brings him to July 1 again. Boys 2, 3 and 4 continue advancing in the same way.

Fourth Year Schedule

21. The fourth year for Boy No. 1 starts off with one month in the drafting room, July 1 to August 1, so that he may gain some idea of how a drawing is made and routed through the shop. At the completion of this time he returns to medium-sized molding for a two-month period ending October 1. Then for the rest of this year he is put to work on large molds—stopping, however, for one month (for this boy, the month of January) for machine shop observation. On July 1 the four boys in this class have completed their time.

22. As we move these boys from year to year, other boys are employed to take their places, so that sixteen boys are always in training, four in each year's class. As each completes his time he will be absorbed by our foundry. Apprentices never are used as laborers.

23. Analyzing this work schedule for costs, since all of the boys are working for regular foremen there is no added cost for work supervision. As all schedule changes are checked by the supervisor of training from the schedule posted in the foundry office, there is no added charge for change supervision.

24. It is true that there is some lost motion at schedule-change time while the boy adapts himself to new work. This is more than balanced, however, if we stop to consider that these boys are taking the place of regular workers and working at a training rate of pay that is, of course, much less than the standard rate. As they go along we find that the boys cultivate the ability to change from one job to another. No cost can be justified at this point.

25. In the last year, the month spent in the machine shop and the month spent in the drafting room are not absolutely necessary, but even here our apprentices more or less pay their way. The machine shop assignment is to the inspection department. The drafting room assignment is to the blueprint department. Thus, all in all, we can see no reason for assigning any cost to maintaining the work schedule.

MAINTAINING SCHOOL SCHEDULE

26. In learning the foundry trade, we all know that nothing can take the place of actual shop work to make a young foundryman familiar with the many facts and methods which constitute a thorough knowledge of this trade. Nevertheless, there are numerous facts and methods that can be easily acquired by reading and study.

27. With this basic fact in mind, we made up a definitely determined school schedule. For the four years that our apprentices are in training they attend classes for a period of four hours

CLARK BROS. CO. FOUNDRY APPRENTICE 1931-1932 OLEAN, N.Y.							
YEAR	NAME	NO	DAY	TIME	SUBJECT	TIME	SUBJECT
FIRST	TERIDURY	1	THURSDAY	8-10 A.M.	DRAWING	10-12 A.M.	MATHEMATICS
	KELLEY	2	"	"	"	"	"
	LIPENTO	3	"	"	"	"	"
	PATTERSON	4	"	"	"	"	"
SECOND	HARRIS	1	WEDNESDAY	8-10 A.M.	DRAWING	10-12 A.M.	MATHEMATICS
	PALMER	2	"	"	"	"	"
	MORABITO	3	"	"	"	"	"
	SCHULTZ	4	"	"	"	"	"
THIRD	SHIVER	1	TUESDAY	8-10 A.M.	TECHNOLOGY	10-12 A.M.	MATHEMATICS
	LIGOURI	2	"	"	"	"	"
	ANASTASIA	3	"	"	"	"	"
	BRENNAN	4	"	"	"	"	"
FOURTH	HENDERSON	1	MONDAY	8-10 A.M.	ENGLISH	10-12 A.M.	ECONOMICS
	OSTERMAN	2	"	"	"	"	"
	BELVEES	3	"	"	"	"	"
	KELLER	4	"	"	"	"	"

FIG. 2—FOUR-YEAR SCHOOL SCHEDULE.

a week, during which time they are taught various related subjects, a determined effort being made to correlate shop and school work correctly. The school schedule was made up so as not to interrupt production any more than was absolutely necessary. As will be seen from the chart of Fig. 2, we do not take all of these boys from the foundry at one time.

Analysis of School Schedule

28. This school schedule we will now endeavor to explain. All classes are of two hours' duration with pay, held during regular shop hours. During the first year we teach these boys elementary

drawing and elementary mathematics, 96 hours being allotted to each subject.

29. Elementary drawing takes up drawing fundamentals, blueprint reading and shop sketching. Everything we use in this course comes from the shop. Elementary mathematics really starts with the simplest elementary definitions and includes fractions, decimals and percentages, measures and weights, powers and roots. All examples make use of foundry terms.

30. During the second year, both the first year subjects are continued—96 hours, as before, are spent on each. Drawing is in a more advanced stage, discussions bringing out how the drawings are to be used in planning new molding and core work. We then take up the arrangement of equipment in a foundry layout. Mathematics continues, bringing out practical measurements, ratio and proportion, formulas, volumes, weights, tables and curves, and so on.

31. In the third year the foundry technology course begins. Perhaps the most important phase of the school training is in this course. "Elementary Foundry Technology," edited by L. A. Hartley, is used as the main reference text and lends itself excellently to this part of the training. Mathematics continues to its completion, dealing with angles, surfaces, belts and speeds, pattern survey, analysis, tapers and drafts, calculations on moisture, permeability, and sand testing and strength. Hours for both of these subjects are again 96.

32. In the fourth year a course is given in vocational English. The boy is taught and shown the advantage of being able to speak and write accurately so that he may make an intelligent report. He is required to prepare such a report on some phase of the work he is doing in the foundry. The last course takes up industrial economics, with an introduction of some of the duties required of men who are in charge of men. Some of these boys should qualify as future foremen, and with this in mind we stress some of the elements of foreman training. Again, the time is 96 hours to each course.

33. This classification might bring up the criticism that 96 hours is not enough for foundry technology, but it will be remembered that in all the other courses the examples and problems are of necessity based on foundry technology and that all the way through this is constantly in the foreground.

34. Of course, cost is involved in maintaining the school schedule, which probably we can best bring out in itemized form. All figures, wherever necessary, are averages for the last five years; all figures are based on our complete quota of 52 boys, and all figures are costs per year per apprentice, as follows:

Cost Per Year Per Apprentice

Salary of School Instructor.....	\$ 66.57
Class Time Allowed Apprentices.....	66.36
Supplies	3.51
Rent of School Building.....	3.46
TOTAL.....	\$139.90

COST OF MAINTAINING DEPARTMENT

35. We now come to the cost of maintaining the apprentice department. The office of the supervisor is in the school building and, according to our scheme, the supervisor is also the apprentice school instructor, so that the charges for these two items are covered under the preceding head. The following figures are again averages for the last five years:

Cost Per Year Per Apprentice

Salary of Part-Time Stenographer.....	\$ 5.74
Supplies	1.18
Bonus paid at completion of time.....	25.00
Miscellaneous (light, heat, etc.).....	3.91
TOTAL.....	\$35.83

TOTAL COST OF TRAINING

36. We now can proceed to sum up our costs to arrive at the total cost of training, the results of which may be presented as follows:

Cost Per Year Per Apprentice

Foundry Layout	None
School Layout	\$ 0.81
Maintaining Work Schedule.....	None
Maintaining School Schedule.....	139.90
Maintaining Apprentice Dept.....	35.83
TOTAL.....	\$176.54

ADVANTAGES AND BENEFITS DERIVED FROM TRAINING

37. We firmly believe that it pays to train foundry apprentices, and even our short experience has shown that many benefits are derived therefrom. A few of the reasons why we believe this statement to be true are given below.

(a) *By training apprentices is found the only way to get a sufficient number of skilled foundrymen.* We all know from experience that it has been no easy matter to hire enough foundry mechanics, especially experienced molders and core makers.

(b) *By training apprentices we are gradually building up a trained personnel.* Our boys learn to appear regularly and punctually. They learn to handle their tools skillfully. They respect authority. They are trained not only individually but also as a group. All of these things point toward a well-knit organization.

(c) *These boys give us a more flexible organization.* If necessary, they constitute a "flying squadron" which helps to meet an urgent demand for a particular part of our product.

(d) *Organized apprenticeship means less labor turnover.* These youngsters—carefully interviewed be-

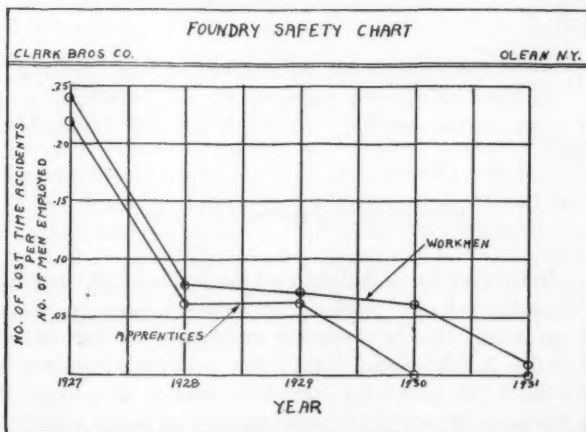


FIG. 3—CHART SHOWING NUMBER OF LOST-TIME ACCIDENTS OF APPRENTICES AS COMPARED WITH THOSE OF OTHER WORKMEN EMPLOYED.

fore being hired, and then trained—are quite sure to become permanent members of our organization. We all know that the ordinary foundryman hired on the exigency of the moment is not likely to remain for any length of time.

(e) *Properly trained apprentices means a group of loyal employees.* As they progress from year to year, these boys come to realize that they are being guided through their trade by the farsightedness of management. Their appreciation is shown by loyalty to the company.

(f) *A marked advantage of this training is that it provides a training school for potential foremen.* Inquire about any successful foundry and you will find that nearly 100 per cent of the foremen are apprentice-trained.

(g) *From a safety standpoint, organized apprenticeship is reducing industrial accidents.* Our foundry safety chart (Fig. 3) shows the apprentice safety curve to be below the workman's curve. To overcome ignorance is to overcome accidents.

(h) *When men are trained in the methods and policies of our own plant they become familiar with our product, our service, our internal good-will and our customers.*

38. All of these things can be obtained only by training from within. As these things are acquired by the personnel, a more efficient organization results. So much for the intangible advantages.

Comparative Apprentice Costs

39. Returning to a dollars and cents basis of comparison, let us visualize two men working in adjacent bays on the same type of molding. One is a regular small-mold worker, the other an apprentice in his second year. One receives \$0.60 per hour, the other \$0.35 per hour (the apprentice rate at that stage), both making the same or nearly the same number of molds a day. The difference in their pay is \$0.25 per hour, or \$2.38 per day, or \$12.13 per week, or \$618.63 per year. Compare this with the cost

of training a boy for one year, namely, \$176.54, which is in the ratio of more than $3\frac{1}{2}$ to 1.

40. From this ratio it will be seen that any allowance for lost motion, instruction, etc., is amply covered. This cites one case only, but the rest of our schedule can be examined in the same manner; in all cases, we know the ratio to be always more than 1 to 1.

CONCLUSION

41. It is not hard to realize that the human element comes first, and we who employ men in the foundry industry try to understand the yearnings of our young apprentices. We think that these same apprentices are beginning to understand the problems, the anxieties and the obligations of management and capital.

42. We have often heard it said that "to train foremen, start with apprentices." This statement is true, for the path to foremanship is more simple and direct when it follows experience gained through systematic training. There is enough evidence of the value of our program to convince us that some of our graduates will become foremen within a few years. Those who do not become foremen will join that group of all-around skilled foundrymen who are so desirable around a foundry.

43. We again return to the question, "How much does it cost to train foundry apprentices?" For us, the answer is that from a straight dollars-and-cents basis we know that our apprentice department is an asset and not a liability. When we compare the apprentices' production cards with their rates of pay and expenses of training on company time, we know that the program is more than paying its way.

44. Gentlemen of the foundry industry, if you want men in your organization who know the handiwork of their trade, who have a broader intelligence—men who are more efficient and easier to get along with, it is to your advantage to inaugurate and efficiently carry on a well-regulated apprentice program, thus maintaining the interest you will receive in return far more than the financial expenditure.

Grain Size and Bond Distribution in Synthetic Molding Sand

By A. H. DIERKER,* COLUMBUS, OHIO

Abstract

This paper deals with the problems of determining the bonding material distribution on the sand grains. To make actual physical tests of bond distribution is difficult, so the author was led to investigate bond distribution by the use of the microscope. Under ordinary conditions it is difficult to distinguish under the microscope between the appearance of the bonding material and the sand grains. Immersing the sample in refractive oil, however, causes the clay to stand out in relief, and its distribution can be determined satisfactorily. Thus the proper time for milling the synthetic sand mixtures can be determined. The length of time depends on the size of the sand grains. In those sands studied this time ranged from 3 minutes to over 1½ minutes. Results of various attempts at measuring surface area of sand grains are given and discussed.

1. It is a fact commonly accepted by molding sand investigators, that a desirable distribution of bond is one in which each individual grain of sand is coated with the proper amount of bonding material, with no excess of this material present as individual lumps or masses. To make actual physical tests for bond distribution admittedly is a difficult matter. It is much easier to assume that bond strength is a function of bond distribution and use the results of the bond strength tests as an expression of bond distribution.

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NOTE: This paper was presented and discussed before one of the sand sessions at the 1932 convention of the American Foundrymen's Association.

2. In our investigations of synthetic molding sands, our failure to correlate such important factors as resistance to spalling and washing, with bond strength, measured either by compression or tension or both, led us to investigate bond distribution by means of the microscope.

A Method for Microscopic Examination of Bond Distribution

3. Under the microscope at 43-diameter magnification, a 65-100 mesh washed Ottawa sand, plus 10 per cent plastic fireclay, milled $7\frac{1}{2}$ minutes, has an appearance similar to that of Fig. 1. It is difficult indeed to determine which is clay and which is quartz.

4. However, if we immerse this mixture in an oil whose index of refraction (1.55) approximates that of quartz, the quartz will tend to be invisible and the clay will stand out in relief, as will be seen by examining Fig. 3-A, which is a sample of same mixture as shown in Fig. 1. The fact that the outlines of the grains are distinct, indicates that they are lightly coated with clay. If they were perfectly clean they would be indistinguishable from the oil.

5. Thus we have a means of determining—qualitatively, at least—clay distribution in certain types of synthetic sands, and the effect on bond distribution of certain factors such as grain size can be determined as in the following experiment.

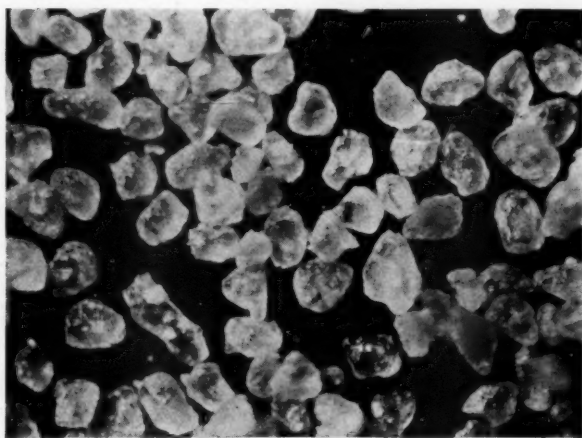


FIG. 1.—PHOTOMICROGRAPH OF 65-100 MESH OTTAWA SAND PLUS 10 PER CENT FIRECLAY MILED $1\frac{1}{2}$ MINUTES. 43X.

Table 1

DETERMINATIONS OF MOISTURE, PERMEABILITY, COMPRESSIVE
STRENGTH AND TENSILE STRENGTH ON WASHED OTTAWA SAND

Grain Size, Sieve Nos.	Moisture, per cent.	Permeability.	Compressive Strength, lbs. per sq. in.	Tensile Strength, grs.
20- 28	1.5	.....	8.0	*
28- 35	1.6	278.4	10.2	*
35- 48	1.6	150.36	10.7	1650
48- 65	1.7	65.37	8.8	1625
65-100	1.9	32.69	9.5	1350
100-140	1.9	19.68	12.0	1425
140-200	1.8	11.57	12.1	1750

* Above 1750.

6. Washed Ottawa sand was carefully separated, by means of hand sieves, into seven different sizes. Ten pounds of each size was milled for 15 minutes in a Simpson laboratory mixer with 10 per cent of plastic fireclay (minus 20 mesh) and the proper amount of water. Small samples of the mix were taken out at intervals of 1½, 3, 6, 9, 12, and 15 minutes. At the end of the 15 minutes' run, determinations were made of moisture, permeability, compressive strength and tensile strength. The results are listed in Table 1.

7. The amount of moisture added was that amount which was considered to give the proper workability to the mix. Naturally, this amount will increase as the grain size decreases.

8. The separate samples were examined microscopically. Figs. 2 and 3 give an idea of the change in appearance as the milling progressed.

Binocular Microscope Used for Examination

9. The micrographs were of necessity made with a monocular microscope. The actual optical examination was made with a binocular microscope, which gives a much clearer picture of the change in distribution than is shown on the photographs. However, we feel that the micrographs give a good picture of the gradual change that takes place in clay distribution as milling progresses.

10. By determining as nearly as possible that point in each

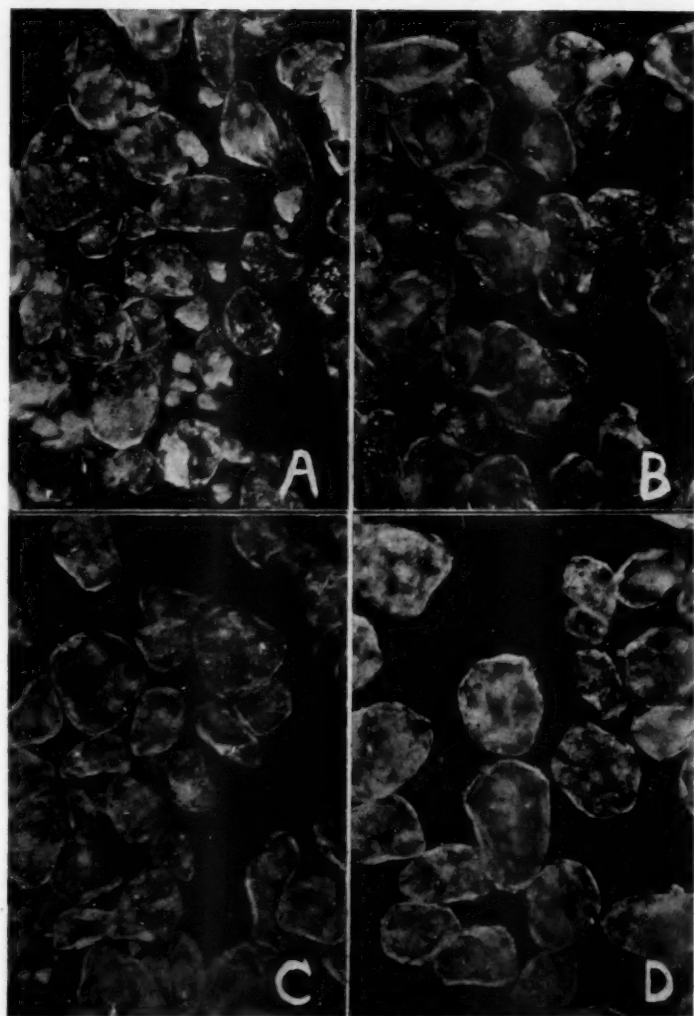


FIG. 2—A: PHOTOMICROGRAPH OF 48-65 MESH OTTAWA SAND PLUS 10 PER CENT FIRECLAY MILLED $1\frac{1}{2}$ MINUTES. B: SAME, MILLED 3 MINUTES. C: SAME, MILLED 6 MINUTES. D: SAME, MILLED 9 MINUTES. ALL SAND MIXTURES IMMERSSED IN OIL OF 1.55 INDEX OF REFRACTION. WHITE OPAQUE PARTICLES ARE CLAY. NOTE HOW THE CLAY GRADUALLY COATS THE TRANSPARENT SAND GRAINS AS MILLING PROGRESSES. 43X.

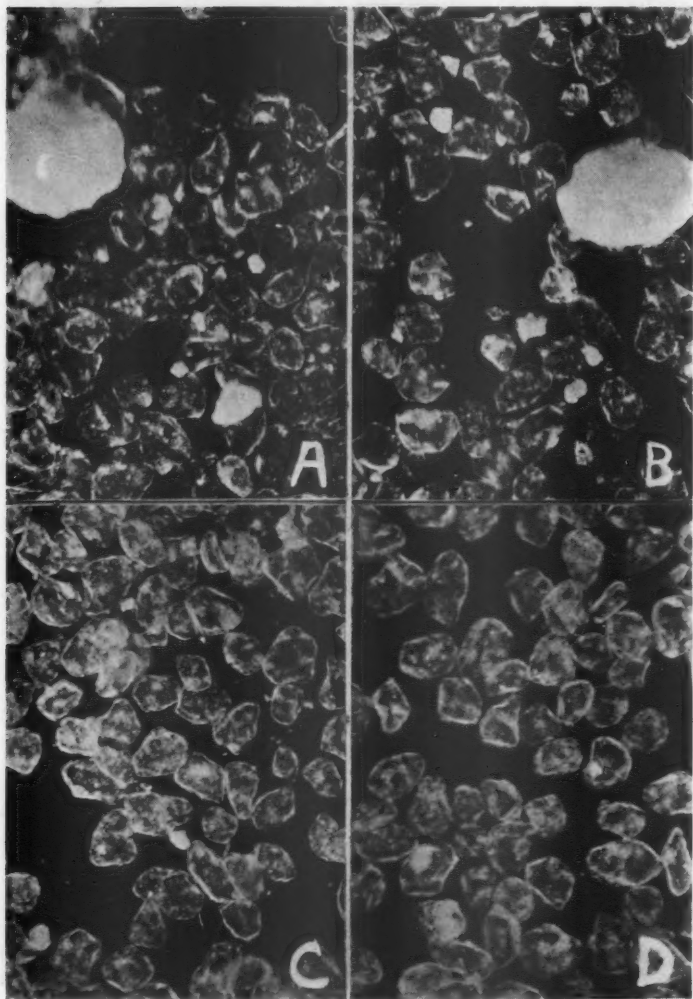


FIG. 3—PHOTOMICROGRAPH OF 65-100 MESH SAND. MILLING TIMES CORRESPOND TO THOSE IN FIG. 2. NOTE THAT BOND DISTRIBUTION IS ABOUT ONE STEP BEHIND THAT OF THE 48-65 MESH MATERIAL. 43X.

sized sand in which excess particles or lumps of clay were absent and the clay fairly uniformly distributed over the sand grains, we get an approximation of the relative milling time necessary for proper distribution of clay bond.

Proper Milling Time Determinable

11. By plotting this determination for each particular grain size against milling time, we get a curve such as shown in Fig. 4. Obviously, no two observers would fix the points at the same place, so that this curve should be considered only as an approximation.

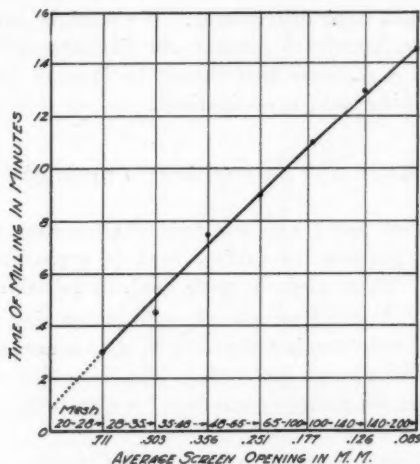


FIG. 4—RELATIVE MILLING TIME REQUIRED TO DISTRIBUTE CLAY BOND ON VARIOUS SIZES OF OTTAWA SAND.

However, it does show clearly that clay bond distribution is a function of grain size as well as of milling time. It is, of course, affected by other factors such as the kind and fineness of the clay, moisture content, etc., but for the purposes of this paper these factors can be ignored.

12. It might be well to mention at this point that we have found it best to examine the sand mixtures with the minimum of agitation and while they are still damp. As the sand dries out, any slight rubbing action will tend to loosen the clay from the sand grains and change the original distribution.

Grain Size Affects Clay Distribution

13. As we know definitely that grain size affects clay distribution, it is interesting to consider the causes for this effect. One marked difference in sands of different grain size is the total surface area, which increases as the grain size decreases. Undoubtedly, more work is required to distribute a given amount of "bond" over a larger surface area than over a smaller surface. Hence, we would expect finer sands to require a longer milling time for proper bond distribution.

14. Our experiments, however, were not carried to the point where we could either prove or disprove a direct relation between surface area and bond distribution. We must be satisfied at this time, therefore, merely to present our findings on surface area, which we feel is a factor that cannot be ignored in interpreting results of molding sand investigations.

Relation of Surface Area to Grain Size

15. Several years ago the writer attempted to obtain an expression of the relative surface area to grain size of washed Ottawa sand. Three methods were used, as follows:

(1) A small sample of each screen size was obtained and the number of grains in each sample counted. From these figures the surface area in millimeters per gram was calculated, assuming for simplicity that all the grains were true spheres.

(2) A number of grains of each screen size were examined under a microscope, and the longest and shortest diameters in the plane at right angles to the line of sight were measured by means of a micrometer eye-piece. In the absence of means for measuring the diameter parallel to the line of sight, it was assumed that this diameter was equal to the shorter of the two actually measured. From these figures the average surface area and volume per grain was calculated. From the average volume, the average number of grains per gram was calculated.

(3) Assuming that all of the grains were true spheres of a diameter equal to the average of the opening of the screen through which they passed and of the

screen on which they were retained, the number of grains and surface area per gram were calculated.

16. We realized, of course, that all of these methods were in error and that the error was on the low side. However, we hoped to secure some relative figures that might prove useful in

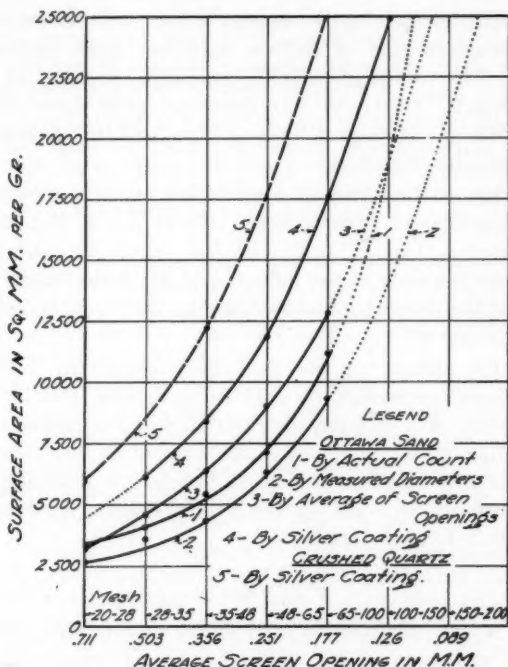


FIG. 5—SURFACE AREA OF VARIOUS SIZES OF OTTAWA SAND AND CRUSHED QUARTZ AS MEASURED BY DIFFERENT METHODS.

connection with problems concerning synthetic molding sands and their use.

17. By referring to Fig. 5 it can be seen that the third method—employing the average of the screen openings—because it gave the highest figures, evidently was the best of the three. This method is the simplest and had been used previously by other investigators. As will be seen, however, it fell far short of giving the actual figures.

Other Investigations on Surface Area

18. Some time later, Gross and Zimmerley¹ found that quartz particles take on a layer of silver of equal thickness when given similar agitation in the same modified mirroring solution. By coating quartz crystals (the surface area of which had been accurately determined) in the same solution with the sized sand and subsequently determining the amount of silver in the various coatings, the surface area of Ottawa sand was quite accurately determined. The results of their determination are plotted as curve No. 4 in Fig. 5. Curve No. 5 in the same figure shows the surface area of crushed quartz particles as determined in the same manner by the same investigators.²

19. The surface area of all molding sands undoubtedly will fall between that of Ottawa Sand (Curve No. 4, Fig. 5) and of crushed quartz (Curve No. 5, Fig. 5). These two curves give a clear picture not only of the influence of grain size on surface area but also of the marked influence that the shape of the sand grains has on this factor.

20. We regret that we have been unable to continue our investigations far enough to establish a definite relation between either surface area or bond distribution and the useful properties of a molding sand. Our excuse for presenting the results of an incomplete investigation is that it presents a new and perhaps useful approach to some of the vital problems confronting investigators in foundry sands.

SUMMARY

21. A new microscopic method for determining bond distribution in simple synthetic molding sands is described. The influence of grain size on clay bond distribution is shown. Results of various attempts at measuring surface area of sand grains are given and discussed.

¹ John Gross and S. R. Zimmerley, "Crushing and Grinding; I—Surface Measurement of Quartz Particles;" *A. I. M. E. Technical Publication No. 46* (1928).

² John Gross and S. R. Zimmerley, "Crushing and Grinding; II—The Relation of Measured Surface of Crushed Quartz to Sieve Sizes;" *A. I. M. E. Technical Publication No. 126*, 1929.

DISCUSSION

ORAL DISCUSSION

CHAIRMAN H. RIES:¹ Mr. Dierker's paper brings out in an interesting way the increasing use being made of the microscope in studying sand. I believe that it probably will be used more extensively in the future.

H. W. DIETERT:² I would like to know how one can get a synthetic sand that would have a fineness of from 140 to 200 and still be workable at 1.8 per cent moisture content. It seems to me that such a sand would take around three and four per cent of moisture.

A. H. DIERKER: All I can say is that we mixed the sand with 10 per cent clay and milled it for the length of time given in the paper, and we added the moisture according to feel. The moistures were determined at the end of the run, and in this case at the start it might have been slightly higher than 1.8 per cent but not more than one or two tenths per cent.

The sand was workable, as indicated by the fact that we were able to run a tensile and compressive strength specimen and get the strength indicated in the table. The fact that these sands were carefully washed and sized and entirely free from fines, may have caused the necessary moisture content to be unusually low.

CHAIRMAN H. RIES: I have heard of some synthetic sands being run with as low a moisture content as 2.5 per cent. Can the author tell me just what that silvering solution is as mentioned in his paper?

A. H. DIERKER: I do not know what the solution is. If you get in touch with Mr. Gross he can give the details of the test, as he ran the determination and we had nothing to do with that part of it.

G. K. EGGLESTON:³ In paragraph 19 it is stated that the surface area of all molding sands undoubtedly will fall between that of Ottawa sand and of crushed quartz, which to me seems a rather broad statement. It may be true, but if one should happen to get a sand of a more rounded grain, or more grains all the same size, the tendency would be to get a lesser surface area than shown on the curves of Fig. 5. As a sand approaches a perfect sphere, there will be less surface per unit volume or weight.

A. H. DIERKER: Regarding Mr. Eggleston's point that the surface areas of molding sands must lie between those two curves, I do not say they must but that they probably will. Undoubtedly no sand will be more angular than crushed quartz, and I quote Dr. Ries as authority for the fact that no one has found a molding sand having a more rounded grain than the Ottawa sand.

CHAIRMAN H. RIES: That is practically true for larger size grains. Since I am quoted on the roundness of the Ottawa sand, let me add that

¹ Department of Geology, Cornell University, Ithaca, N. Y.

² Research Engineer, U. S. Radiator Corp., Detroit.

³ Detroit Lubricator Co., Detroit.

those round grains are only found in abundance in the larger sizes. In the smaller sizes of the Ottawa sand, the round grains disappear. This is true of any sand; the small sizes invariably are either angular or sub-angular, and as a rule it is only the larger sizes that are round. Still, in the Ottawa sand the general roundness is reflected somewhat in the shape of the grains.

H. W. DIETERT: Mr. Dierker, which method of measuring the surface area is best?

A. H. DIERKER: I would assume that the method of Mr. Gross is best; to my knowledge it is the nearest approach anyone has made to obtaining the true surface area of quartz sand. Of the other three methods, it would seem that the average of the screen openings is the best method, because it is the closest to Mr. Gross' determination and is the method used frequently by other investigators.

MEMBER: Suppose I am entering the foundry business and want to make certain castings, for example, ornamental lamps, and I want to know what kind of sand I should use in making that casting. Can anyone tell me how to specify that sand?

H. W. DIETERT: I believe that is the ultimate goal we are striving for, to be able to make specifications for sands which can be used to produce castings of any certain type. However, we cannot do this as yet because we do not know how to specify all the grading factors. Perhaps we can in ten years.

MEMBER: That is what I want to bring out; we do not know. No one can tell me what to use in the foundry—some of the factors, yes, but not all. Why should we not get to that point? We specify some particular sand, such as an Ottawa sand, that has the proper grain size. I believe that if we could give the foundryman this complete information, we would do a great deal of good.

CHAIRMAN H. RIES: The Committee on Tests at present is working on the development of methods whereby we can describe the proper sand, and when we get those methods perfected we can come to specifications.

H. W. DIETERT: I feel that we have developed far enough now so that we can specify the permeability, the bond and the fineness. In ten years probably we will have many other descriptions for the other desired properties of the molding sand.

High-Silicon Pig Iron for Malleable Iron Manufacture*

By CARL F. JOSEPH,† SAGINAW, MICH.,
and A. L. BOEGEHOLD,** DETROIT.

Abstract

The occurrence of "speckled fracture" in annealed malleable-iron castings is described and the investigation to discover the cause of speckled fracture is given. The cause is traced to variations in the quality of the high-silicon pig iron used in the cupola charge. Chemical, spectroscopic and metallographic analyses show that the difference in the pig irons is of a physical nature and manifests itself in the amount of steadites in the microstructure.

1. This paper is devoted to certain irregularities in physical properties and appearance of fracture observed in certain heats of malleable iron which exhibited an unsatisfactory structure after annealing. The malleable iron in question is made by a duplex process in which steel, white-iron sprue and high-silicon silvery pig iron is melted in a cupola, desulphurized in a large mixing ladle, transferred to a direct-arc electric furnace, superheated and cast.

2. The white iron castings made from this metal are annealed for 96 hours in a continuous annealing kiln. The malleable iron so made normally exhibits a smooth, close-grained, black, silky fracture and possesses ductility which gives 12 to 18 per cent elongation in the standard tensile test bar.

*A. F. A. exchange paper presented before the International Foundry Congress at Milan, Italy, held Sept. 12-27, 1931.

†Metallurgist, Saginaw Malleable Iron Co.

**Metallurgist, General Motors Research Laboratories.

NOTE: This paper was presented and discussed before the session on malleable iron at the 1932 convention of the American Foundrymen's Association.



FIG. 1—MALLEABLE IRON SPECIMENS SHOWING THE DIFFERENCE BETWEEN "SPECKLED FRACTURE" (ABOVE) AND NORMAL FRACTURE. BOTH SPECIMENS SHOWN AT X3.

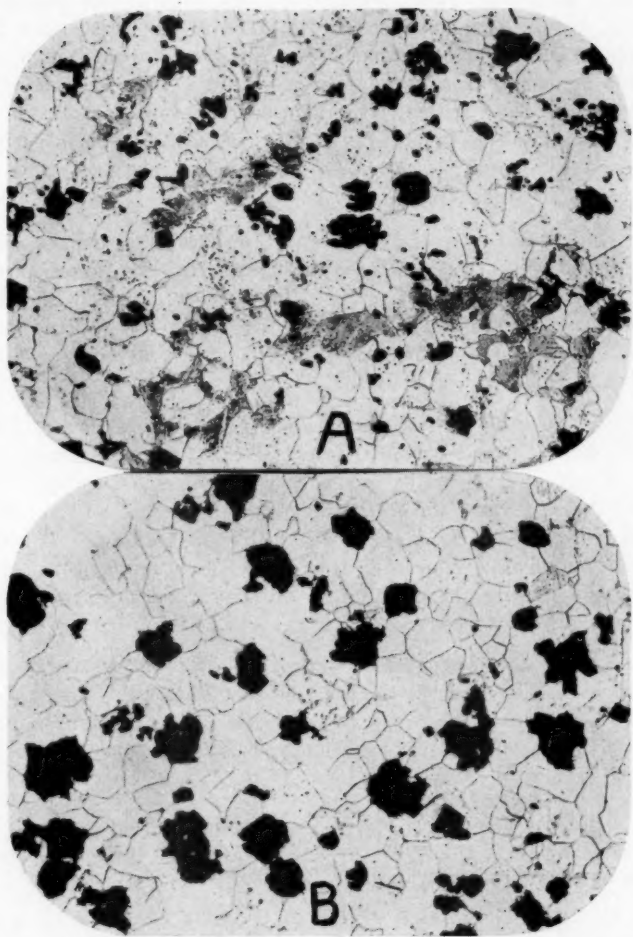


FIG. 2—MICROSTRUCTURES OF MALLEABLE IRON WHICH POSSESSES A NORMAL CLOSE-GRAINED BLACK FRACTURE. X100. A (ABOVE): EDGE OF SPECIMEN. B: CENTER OF SPECIMEN.

3. To obtain the uniformity of quality in the white-iron casting so that it always responds properly to the relatively short 96-hour annealing cycle giving the type of fracture described above, requires rigorous metallurgical control. Test bars for fracture examination poured every hour are put through the annealing cycle in advance of the castings poured during the same hour. Any irregularity in appearance of the fracture of these test bars after annealing prompts unusually close inspection of the corresponding castings to see whether reannealing or rejection is necessary.

4. About two years ago, some test bars and castings came through annealing and exhibited a type of fracture which started the investigation reported here. This fracture, instead of being fine-grained, black and silky, was coarse-grained, peppered with minute greyish-white specks and lacked the silky sheen of the standard fracture.

5. Fig. 1 shows this fracture compared with a normal fracture. This departure from the normal fracture might escape the eye of the inexperienced observer were it not called to his attention. Fig. 1 shows the difference between normal and speckled fracture more clearly than does visual examination of the fractures themselves. When this type of defect is more pronounced, there are small bright areas in the fracture which are apparent to the most inexperienced eye.

6. The microstructure of iron with this type of fracture appears in every respect the same as that of normal quality iron unless the trouble is allowed to persist for more than three days, at which time pearlite and cementite begin to appear in the annealed structure.

7. The photomicrographs of Fig. 2, *A* and *B*, show the microstructure of malleable iron possessing a normal fracture. Fig. 2-*A* shows the rim and Fig. 2-*B* the center.

8. Photomicrographs of Figs. 3-*A*, 3-*B*, 4-*A* and 4-*B* show the structure of speckled-fracture malleable iron after it has continued for more than three days production. These show a heavy pearlite rim, pearlite in small quantities in the center, and large temper-carbon nodules.

9. On account of the minute greyish-white specks sprinkled through the fracture, we will refer to this fracture as "speckled

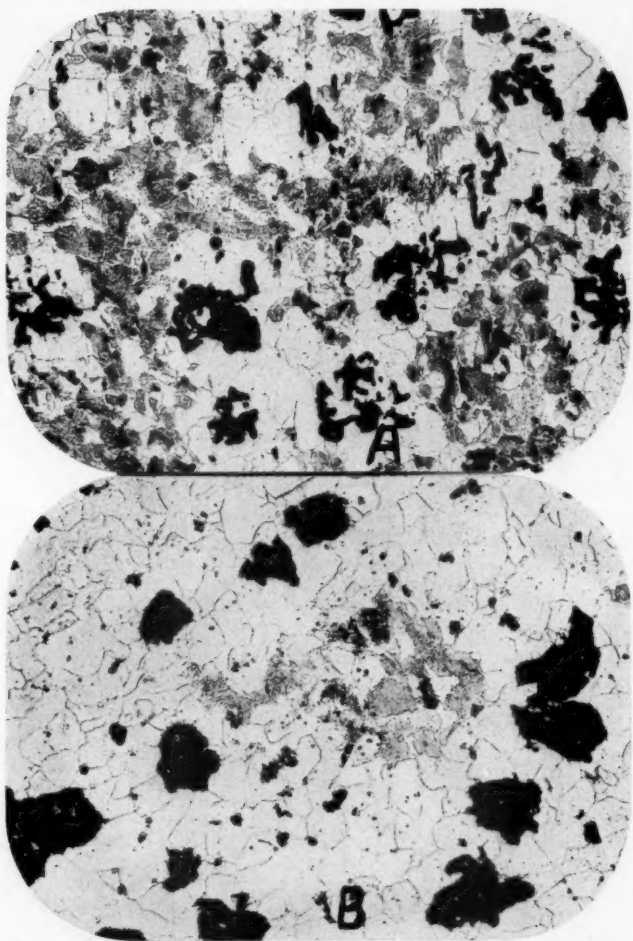


FIG. 3—MICROSTRUCTURES OF MALLEABLE IRON MADE WITH PIG IRON OBTAINED FROM BURDEN CONTAINING HIGH-PHOSPHORUS ORE. FRACTURE OF THIS IRON HAS SPECKLED APPEARANCE. X100. A (ABOVE): EDGE OF SPECIMEN. B: CENTER OF SPECIMEN.

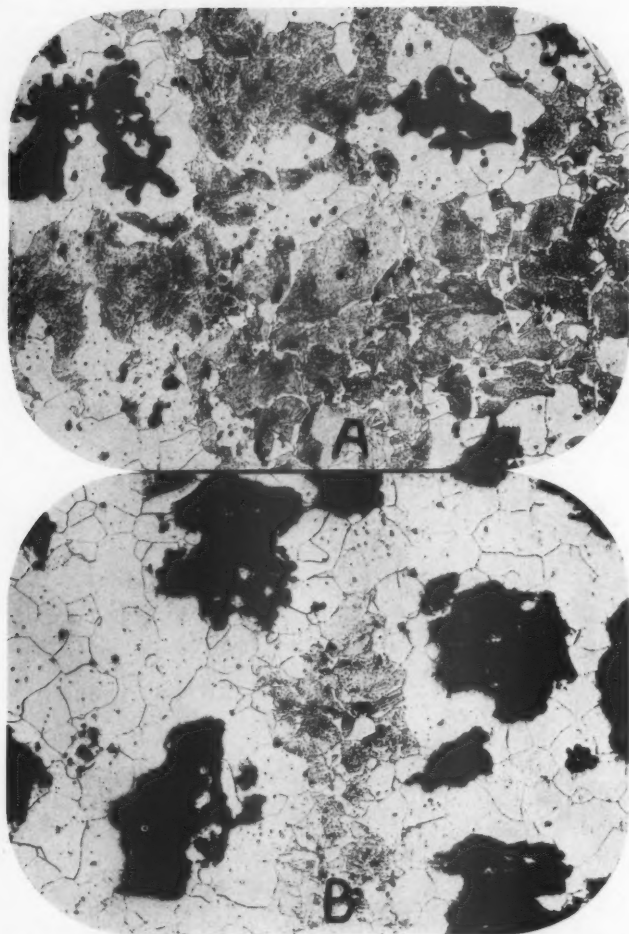


FIG. 4—MICROSTRUCTURES OF MALLEABLE IRON WHICH POSSESSES A COARSE SPECKLED FRACTURE. X100. A (ABOVE): EDGE OF SPECIMEN. B: CENTER OF SPECIMEN.

fracture" in the remainder of this paper, to distinguish it from the "normal" fracture already described. Iron exhibiting speckled fracture usually possesses about 4 per cent lower tensile strength, and elongation drops to 10 to 13 per cent in 2 inches and requires reannealing to make it satisfactory for machining.

10. When speckled-fracture castings first made their appearance, every phase of the manufacturing process was subjected to close examination. One of the first things looked for was the presence of undesirable elements such as chromium, tin and the like in the melting stock.

11. It was found that some of the steel scrap contained chromium. Analysis of the castings showed as high as 0.04 per cent chromium, and it then was believed that the trouble was found. The steel scrap containing chromium was eliminated, but the trouble still continued with only 0.020 per cent chromium in the castings, which is less than the normal 0.03 per cent present in iron exhibiting the normal fracture.

12. One of the authors¹ has demonstrated that pig irons of similar chemical composition may differ in quality and that this difference may persist through the cupola remelting operation and affect the properties of cast iron made therefrom. Additional testimony regarding the variation in quality of pig irons of the same composition and their effect on the quality of the iron made therefrom, is given in the *Transactions* of the American Institute of Mining and Metallurgical Engineers² and the *TRANSACTIONS* of the American Foundrymen's Association.³

13. These findings strengthened a suspicion that the pig iron was a factor in causing speckled fracture. After checking every other phase of the manufacture of these castings without discovering the cause for speckled fractures, it was decided to try some pig iron from another blast furnace. The only pig iron used in the cupola charge is silvery pig iron containing 9.5 per cent silicon and 2.50 per cent manganese, and this pig iron constitutes only 12.5 per cent of the cupola charge.

14. A shipment of high-silicon pig iron was obtained from a different blast furnace. The annealed castings from the first

¹ A. L. Boegehold, *Quality of Pig Iron and Castings as Affected by Blast Furnace Practice*, *TRANSACTIONS* A. F. A. (1929), vol. 37, p. 91.

² *Transactions* American Inst. Mining and Metallurgical Engineers, vol. 75, pp. 443-456, 482-496.

³ *TRANSACTIONS* A. F. A. (1927), vol. 35, pp. 328-355.

day's cast in which this new pig iron was used showed the normal fracture and physical properties. So long as this pig iron was used, the annealed iron showed a normal fracture.

15. After using the new pig iron for a few weeks, the old pig iron was substituted and the trouble reappeared. Castings made beginning the third day after the change to the old iron, showed speckled fracture after annealing.

16. Several times, these two lots of pig iron were interchanged in the cupola charge and, each time, the speckled fracture appeared when using the old pig iron and good fracture resulted when the new pig iron was used. Even when the 12.5 per cent pig iron in the charge consisted of 6.5 per cent of the new pig and 6 per cent of the old pig, the speckled fracture appeared.

17. These experiments established to our satisfaction that the character of the high-silicon pig iron was responsible for the speckled fracture. Establishment of this fact made it clear that it would be necessary to test incoming pig iron in some way to find out whether its use would result in castings with speckled fracture. It became necessary, then, to find the element responsible in the pig iron or to find some characteristic of the pig iron which it possessed in common with an ability to produce speckled fracture or normal fracture in the malleable iron made from it.

ELECTRIC FURNACE MELTING TESTS

18. Additional proof that coarse and speckled fracture in malleable iron was inherited from some quality in the pig iron was obtained in a series of melting tests where small heats were melted in a high-frequency furnace using steel, washed metal and pig iron as melting stock. The pig iron used in these melts was the same as had been used in production.

19. Pig iron which produced normal fracture malleable iron in production, we will call "Type N" pig iron in the remainder of this paper, and pig iron which produced speckled fracture in production we will call "Type S" pig iron. Three sources from which high-silicon silvery pig iron is obtained have supplied both Type N and Type S pig iron at one time or another.

20. Test bars poured from melts made with Type S pig iron showed the speckled and coarse fracture after annealing. Test bars poured from melts made with Type N pig iron showed the normal good fracture after annealing. The fact that these

results were obtained eliminates anything in the production melting procedure as a possible cause of the speckled fracture which we observed.

MICROSTRUCTURE OF PIG IRON

21. Differences between Type S and Type N pig iron were sought in the microstructure. Here it was noted that particles of a white constituent were quite numerous in Type S iron and practically absent in Type N iron. Heat tinting as recommended

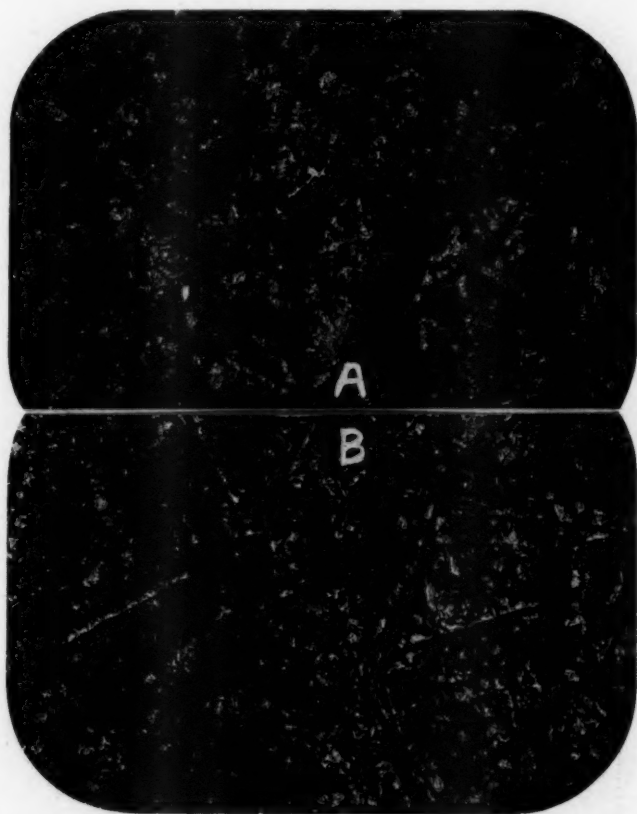


FIG. 5—MICROSTRUCTURES OF TYPE N PIG IRON FROM FURNACE "B", SHOWING ABSENCE OF STEADITE. X100.

by Stead indicated that these were phosphorus rich. They will be referred to hereafter as "steadite."

22. The photomicrographs of Figs. 5-7, inclusive, illustrate the difference in microstructure of these pig irons. The arrangement of graphite varied considerably in the different heats of pig iron, but no relation of graphite arrangement to quality of the iron could be observed.

23. Figs. 5-A and 5-B show the structure of pig irons which resulted in the normal quality of malleable iron. The etching



FIG. 6—MICROSTRUCTURES OF PIG IRON FROM FURNACE "B" MADE FROM BURDEN CONTAINING HIGH-PHOSPHORUS ORE. SHOWS NUMEROUS STEADITE AREAS. X100.

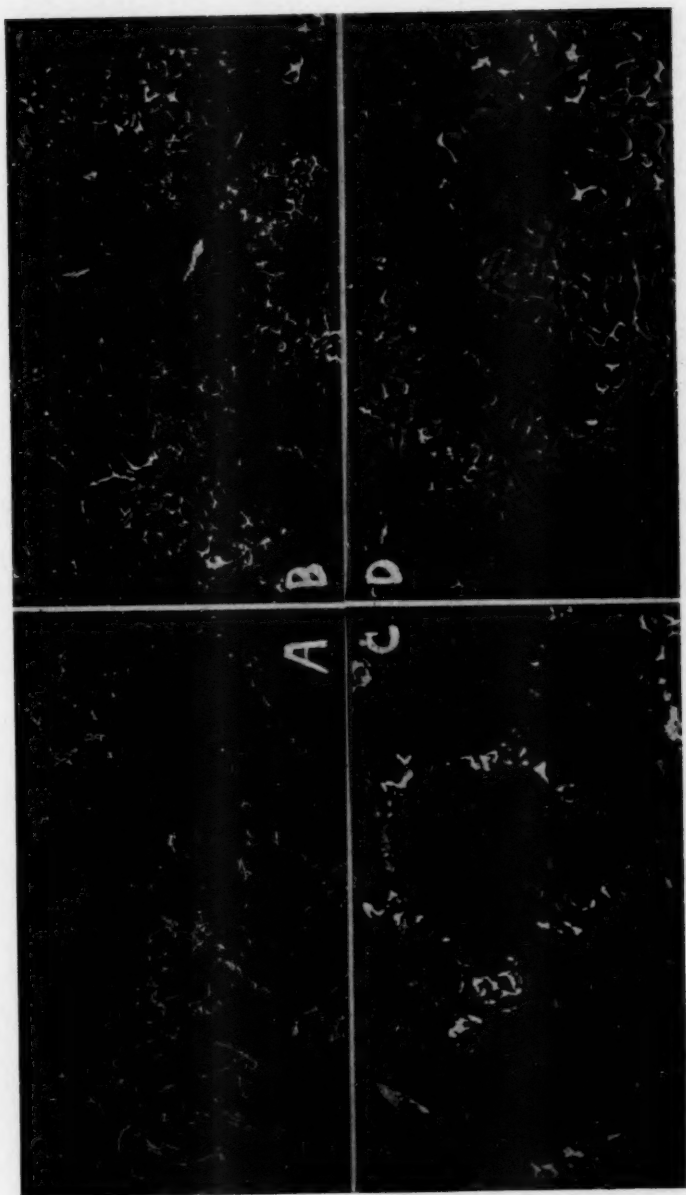


FIG. 7—MICROSTRUCTURES OF TYPE S PIG IRON FROM FURNACE "A". SHOWS LARGE AMOUNT OF STEADITE. X100.

reagent used was a 10 per cent solution of hydrofluoric acid in a 4 per cent solution of nitric acid in alcohol. This was adopted because it showed most clearly the presence of steadite. It will be noted that no steadite appears in these two structures.

24. Figs 6 and 7 show the structure of high-silicon pig irons which resulted in malleable iron with speckled fracture. These all show a considerable quantity of steadite.

EFFECT OF ALLOY LADLE ADDITIONS TO MALLEABLE IRON

25. Small amounts of tin, vanadium, titanium, chromium, molybdenum, tungsten, copper, cadmium, cobalt, lead, manganese, zinc and aluminum were added in the ladle to the molten iron used to make white-iron castings. This was done to determine the effect of elements that might come into the iron with steel scrap used for raw material. Irons containing these alloys were given the regular anneal and the fracture examined to see if the addition of any of these elements produced a speckled fracture. Addition of 0.03 per cent titanium produced a coarse fracture more nearly resembling the speckled fracture in question than the fracture produced by any other alloy addition tried.

Vanadium.

26. Addition of 0.01 per cent vanadium to the ladle resulted in speckled fracture in iron annealed at 1650 degs. Fahr., and 0.13 per cent vanadium resulted in white fracture after annealing. Vanadium to 0.05 per cent was required to produce speckled fracture in iron annealed at 1750 degs. Fahr., and 0.21 per cent caused white fracture after annealing.

Chromium.

27. Small percentages of chromium did not produce speckled fracture, but 0.07 per cent produced a pearlitic rim and 0.095 per cent developed pearlite and cementite in both rim and core. With up to 0.05 per cent chromium added, the fracture was normal after annealing.

Chromium and Vanadium.

28. Addition of 0.03 per cent chromium and 0.005 per cent vanadium produced speckled fracture in iron annealed at 1650 degs. Fahr., while addition of 0.07 per cent chromium and 0.011

per cent vanadium produced speckled fracture in iron annealed at 1750 degs. Fahr.

Molybdenum.

29. Addition of 0.12 per cent molybdenum produced speckled fracture in iron annealed at 1650 degs. Fahr., and pearlitic rim in iron annealed at 1750 degs. Fahr.

Tungsten.

30. Up to 0.12 per cent tungsten added to the iron caused no change from the normal annealed structure. No tungsten could be detected by chemical analysis in the iron.

Copper.

31. Copper up to 0.30 per cent added to the iron made no change in the normal fracture.

Cadmium.

32. Cadmium was added only up to 0.11 per cent because of the explosive effect of oxidation of the cadmium when superheated by the molten iron. This amount had no influence on the fracture, presumably because no cadmium entered the metal.

Cobalt.

33. Cobalt up to 0.25 per cent produced no change in appearance of the fracture.

Lead.

34. Addition of 0.29 per cent lead had no effect on fracture. Probably no lead remained in the iron.

Zinc.

35. Addition of zinc caused so much spitting and boiling that no tests were made.

Aluminum.

36. Addition of 0.05 per cent aluminum caused mottling of the hard iron casting and reduced the strength and elongation of the annealed iron.

Tin.

37. Addition of 0.03 per cent tin produced a hard rim and greatly reduced ductility.

Manganese.

38. Manganese up to 0.50 per cent had no effect on the core structure, but above that amount it caused a heavy pearlitic rim.

Titanium.

39. The presence of titanium over 0.015 per cent caused the iron to have a coarse-grained fracture and pearlitic rims. The presence of 0.03 per cent titanium retarded annealing so that cementite and pearlite were present in the microstructure. Spectroscopic examination of the Type N and Type S pig irons failed to show any differences that would account for the occurrence of speckled fracture in the malleable iron made therefrom. Chemical analysis also failed to show the presence of any of the elements which produced speckled fracture after ladle additions.

40. After speckled fracture had been eliminated in production by using pig iron from another source which we will call "B" furnace, three more shipments, each consisting of series of casts totaling about 4000 tons of pig iron, were obtained over a period of a year from the same source with equally good results. The phosphorus content of these heats varied from 0.15 per cent to 0.30 per cent, and the phosphorus in the malleable iron varied accordingly from 0.06 per cent to 0.10 per cent. It was decided to have subsequent shipments of pig iron contain 0.30 per cent phosphorus, because it was believed that the higher phosphorus white iron handled better in pouring.

41. Thus, the next pig iron obtained from "B" furnace was made with 0.30 per cent phosphorus. To accomplish this, a high-phosphorus ore containing 5.41 per cent phosphorus was added to the burden. The high-phosphorus ore constituted 1 per cent of the burden.

42. When this pig iron was used, although the white iron contained only 0.10 per cent phosphorus, the speckled fracture appeared again in the annealed iron. Another cast of pig iron was made with an identical burden, with the exception that the 1 per cent of high-phosphorus ore was left off. This pig iron was used and resulted in the normal silky close-grained, black fracture.

43. This development made us ask whether the high phosphorus, or some other element in this particular ore, was responsible for the trouble. The pig iron microstructure showed the steadite was exactly the same as in other pig irons which produced speckled fracture in the malleable iron. (See Fig. 6, *A* and *B*). The resulting higher phosphorus in the iron could not be blamed for the trouble, because previous heats of iron which had showed speckled fracture had low phosphorus content (0.07 per cent), and because some of the previous heats which showed normal fracture had as high as 0.12 per cent phosphorus.

44. The high-phosphorus ore was found to contain 8.74 per cent titanium. This resulted in 0.12 per cent titanium in the pig iron and 0.024 per cent titanium in the malleable iron. This

Table 1

NITROGEN AND OXYGEN DETERMINATIONS OF PIG IRON			
Pig Iron No.	Type of Fracture in Malleable Iron Resulting.	Nitrogen, per cent.	Oxygen, per cent.
1	Normal	0.002	0.008
		0.002	0.014
7	Very slightly speckled	0.001	0.002
		0.001	0.004
6	Speckled	0.002	0.006
9	Very speckled	0.001	0.009

amount of titanium added in the ladle to good iron will produce speckled fracture.

45. On the other hand, malleable iron having a normal fracture has been made from pig iron containing 0.12 per cent titanium. This titanium, instead of coming into the pig iron entirely from one ore very high in titanium, came from all the ores in the burden, each of which carry a moderate amount of this element.

NITROGEN AND OXYGEN CONTENT

46. Samples of Type N and Type S pig irons were analyzed for the presence of oxygen and nitrogen. These determinations were made at the U. S. Bureau of Standards, through the kindness of Dr. J. G. Thompson. Nitrogen and oxygen were determined by the vacuum fusion process, with the results shown in Table 1. It is apparent from these results that neither the oxygen nor nitrogen content of the pig iron is responsible for the speckled fracture condition.

Table 2

COMPOSITION OF BURDEN CALCULATED FROM COMPOSITIONS OF ORES

Cast No.	Kind of Iron	Fe	SiO ₂	Al ₂ O ₃	CaO	MgO	Mn	P	Ti
1	Type N	42.12	17.29	2.19	0.36	0.30	1.52	0.097	....
3	Type N	47.08	18.79	1.623	1.184	0.287	1.42	0.152	.....
4	Type N	45.43	19.64	1.252	0.995	0.477	1.53	0.056	.....
5	Type S	57.52	13.93	1.287	0.568	0.346	2.073	0.060	.....
6	Type S	52.10	17.55	1.635	1.340	0.355	1.47	0.114	.....
7	Type S	42.37	16.95	1.888	0.802	0.301	1.54	0.0874	.....
8	Type S	46.09	18.83	1.270	0.996	0.452	1.158	0.118	.....
9	Type S	54.80	20.54	2.34	0.500	0.281	1.534	0.107	.....

47. Ever since it was determined that pig iron quality was responsible for the occurrence of speckled fracture, it has been customary to have a representative present at the blast furnace during the casting of all high-silicon silvery pig iron bought for the manufacture of malleable iron. A record is obtained including everything pertaining to the manufacture of that pig iron.

48. Similar information has been obtained regarding the making of pig iron which was used before and during the time when speckled fracture was first observed. The blast furnace which made the iron being used when the trouble was first observed has supplied additional heats of pig iron of which a blast furnace record was also obtained.

49. To allow comparison of the conditions attendant upon the making of these heats of pig iron, data is given in Tables 2, 3 and 4 concerning those details of blast furnace operation wherein differences existed in the practice at the two furnaces. This data does not help us to decide what quality in these pig irons is responsible for speckled fracture, but it does show that there was considerable variation in conditions during the making of these

Table 3

ANALYSIS OF PIG IRON OBTAINED FROM BURDENS IN TABLE 1

Cast No.	Si	P	Mn
1	9-9.5	0.22-0.27	2.0-2.5
3	8.5-9.25	0.24	2.15-2.4
4	8.5-10.0	0.14	2.2-2.4
5	9-9.5	0.15-0.18	2.0-2.5
6	9.2-10.0	0.22	2.2-2.6
7	8.75-9.5	0.24	2.2-2.5
8	9.0-10.0	0.26-0.30	2.0-3.0
9	7.95-9.80	0.25-0.30	2.30-2.6

Table 4
BLAST FURNACE OPERATING STATISTICS

Fracture of Malleable Iron Made.	Normal.	Normal.	Normal.	Speckled.	Speckled.	Speckled.	Speckled.	Speckled.
Slag Composition, per cent { SiO_2 38.5 Al_2O_3 15.0	40.96	41.42	38.0	36.77	41.10	40.80	39.89	
Ore Charge, lbs., 15,900	10,400	10,800	14,100	17.28	14.11	10.10	12.57	
Coke per lb. of ore, 0.7	0.72*	0.72*	0.60	13,800	13,400	11,000	13,200	
Coke per lb. of iron made, 1.4	1.42	1.48	1.005	0.69	0.70	0.68*	0.712	
†Combustibility of coke { Temp. rise, degs. Fahr., 241 Rate of temp. rise per 250 degs. Fahr., min., 4.4	.....	.....	.....	1.23	1.52	1.31	1.15	
Cu. ft. air per lb. coke, 57.5	67.5	64.5	59.5	240	.....	.....	.....
Iron made per hr. per sq. ft. cross-sec. area at max. diam., lbs., 58	70.0	67.1	74.5	5.4	.....	.....	.....
Cu. ft. air per lb. iron made, 80.5	96.0	95.5	59.8	59.0	54.0	56.5	67.8	
				60.0	50.9	63.2	62.5	
				72.6	82.0	74.0	78.0	

* 26.7 per cent high-volatile coal.

† Procedure given in paper referred to in footnote ¹ in paragraph 12.

pig irons. It is reasonable to assume that these variations will have a definite effect upon the quality of the high-silicon silvery pig iron produced.

50. An outstanding difference is noted in the slag composition. In general, the irons causing speckled fracture were made with a slag higher in total acids and with a high alumina content in the slag. Heat No. 8 is an exception to this. This is the heat in which a high-phosphorus ore was used to which speckled fracture is attributed. This ore contained 5.41 per cent phosphorus and 8.74 per cent titanium.

51. Another heat of pig iron, made exactly the same as heat No. 8 (except for the omission of the high-phosphorus ore), resulted in pig iron which made malleable iron with a normal fracture. Another important difference in two of the heats which gave Type N pig iron is that 26.7 per cent of the fuel used was high-volatile coal containing approximately 38 per cent volatile hydrocarbons.

52. In this connection, the work of Stalhane and Malmberg⁴ is of interest. They investigated the reduction of iron ores by hydrogen and mixtures of hydrogen and carbon monoxide. They found that the rate of reduction in pure hydrogen was seven times as fast as in pure carbon monoxide, and that addition of carbon monoxide to hydrogen slows up the rate of reduction quite markedly.

53. This is merely mentioned to indicate that the use of high-volatile coal as blast furnace fuel may be of value through the more powerful reducing ability of the hydrocarbons contained. It should be pointed out, however, that Type N. pig iron has been made by another furnace where coke was the only fuel used.

SUMMARY AND CONCLUSIONS

54. The occurrence of speckled fracture in malleable cast iron is described, and its cause is traced to some unknown quality in the pig iron used as raw material.

55. The microstructure of pig iron which causes speckled fracture exhibits a considerable amount of steadite, while pig iron which results in normal fracture malleable iron shows no steadite.

⁴ Bertil Stalhane and Tore Malmberg. *Jernkontorets Ann.* 114, 609-722, 1930. "Investigation of the Reduction of Iron Ores by Hydrogen and by Hydrogen and Carbon Monoxide."

56. In one instance, the undesirable quality in the pig iron is traced to the use in the blast furnace burden of a small quantity of ore containing 5.41 per cent phosphorus and 8.74 per cent titanium.

57. It is suspected that the undesirable quality in other pig irons may be due to the quality of ores used and to something in the blast furnace operation.

58. To prevent the use of undesirable pig iron in production, it may be tested by examination of the microstructure and by making small electric-furnace heats which, when annealed, can be examined for quality of fracture.

DISCUSSION

ORAL DISCUSSION

FRED L. WOLF:¹ The photomicrograph of Fig. 3 looks very much like a sample I saw recently of a normal malleable iron having about 2.50 to 2.60 per cent carbon and 0.90 per cent silicon that had been annealed. This iron was given the normal anneal and then brought through the critical range, around 1550 degs. Fahr., very quickly, at about 200 degrees per hour.

A. L. BOEGEHOLD: Of these two photomicrographs of Fig. 3, one represents the rim; the lower one, the center of the bar. This particular condition, with the small amount of pearlite in the center, is what shows up in this speckled iron if we use the pig iron for more than three or four days, after which time the speckled condition gets so bad that pearlite begins to show in the microstructure. When the speckled fracture first appears, there is no pearlite in this microstructure at all.

C. F. JOSEPH: The cooling rate of this iron, from approximately 1600 degs. Fahr. down to 1500, was about 30 degrees per hour; from 1500 degs. Fahr. down to 1360, it was about 20 degrees per hour. Under 1360 degs. Fahr., of course, it was cooled more slowly.

MEMBER: What pig irons cause this trouble and what pig iron do not cause it? Do pig irons from one source cause it and, at times, pig irons from all sources?

C. F. JOSEPH: The company which made the iron that caused the trouble at the start had made our iron for some two or three years, and

¹ Chief Engineer and Technical Superintendent, Ohio Brass Co., Mansfield, Ohio.

during that time the iron was perfectly satisfactory. Then they started to produce this bad iron, and all at once we had trouble. We then changed over to iron from another producer and ran along a year or two with wonderful iron. Then they, too, ran into some difficulty.

Consequently, this trouble does not seem to be characteristic of any one company's iron. I think there is possibility of all the producers running into trouble from time to time.

MEMBER: What method do you use to determine in advance what pig iron is satisfactory and what is not?

C. F. JOSEPH: So far, the best method seems to be to examine a piece under the microscope; if the microscope does not reveal the presence of steadite, we feel confident that the pig iron is good. The photomicrographs of Fig. 5 show a normal structure that indicates the iron is good, as it shows the absence of steadite. The micrographs of Fig. 6 show the presence of the steadite areas.

The iron that gave us the worst trouble is the iron marked *D* in Fig. 7. That iron was run half a day and during the very first half-day's run the castings came out speckled. In fact, they came out so badly speckled that even after putting them through the kiln the second time, they still were no good. Usually we were able to obtain usable castings after running them through the furnace twice, although they are not as good as they should be.

We now can pick out the pig iron that gives us trouble and the iron that does not. If we have any iron that shows that it will give trouble, we do not run it over one day. Then we switch over to an iron that is good and run that for two or three days, switching back to the first iron for only one day. By following this procedure we are able to produce good iron all the time.

MEMBER: As I understand it, this steadite is more or less included in the cementite formations.

C. F. JOSEPH: That is the way it appears.

MEMBER: With simple 2 or 3 magnification observation, when your casting appears to have, after the anneal, a more or less lacy structure through it, would this indicate that it is under-annealed or that it will not take an anneal?

C. F. JOSEPH: It shows more of a gray than a white structure.

MEMBER: Would it be iron which, in the beginning, could be easily misinterpreted as under-annealed normal iron?

C. F. JOSEPH: That is correct.

MEMBER: Do I understand correctly that the steadite has a tendency to migrate into the iron-carbide (Fe_3C) formation that you get in the iron?

C. F. JOSEPH: In the white cast iron I understand this steadite is in the form of a ternary alloy, which consists of Fe_3C , Fe_3P , and iron. That ternary alloy is a hard thing to decompose in annealing, and I be-

lieve that this grayish structure is due to the ternary alloy, which is rather hard to break down. We have done considerable work on this problem in the past few months, but I am not yet prepared to say exactly what the answer is.

MEMBER: If you took the casting with the steadite formation (which caused you to feel that it was unsatisfactory) and put it through another cycle of anneal, could you not produce the trouble there by breaking down your original crystal boundaries and actually make the iron worse than it was originally? In other words, you break down the minute crystals and create one large crystal, yet you still may not eliminate the difficulties due to the steadite.

C. F. JOSEPH: Reannealing does not seem to help the structure much, but it does seem to make it easier to machine.

As to the crystal boundaries, we have looked at specimens under the microscope and it does not seem to change except that the pearlite does not seem to occur in the first day's run of this iron. After the iron is run two, three or four days, the pearlite seems to form. We have run it as high as eight and nine days just for test purposes, and the pearlite seems to increase the longer we run it. However, for the first day or two the microscopic structure appears fairly normal; there is no pearlite to mention.

I believe all of us have had trouble in the past with castings that showed possible rims. I am positive that a great deal of rim trouble is caused by the raw material, whether it happens to be the pig iron or the steel.

MEMBER: How far down in the phosphorus scale did the authors go and still find this tendency on the part of the phosphorus?

C. F. JOSEPH: We have had high-phosphorus iron (0.30 per cent) that did not show the trouble, and we have had high-phosphorus iron (around 0.30 per cent in pig iron) that did show the trouble. Also, we had low-phosphorus iron (around 0.15 per cent) that showed the trouble, and some that did not show it.

The phosphorus content of the casting itself will vary only from 0.068 per cent to possibly 0.088 per cent. This is because we use only between 10 and 12.5 per cent of pig iron in our charge, and the phosphorus in the iron will vary only about $1\frac{1}{2}$ or 2 points. The trouble is caused not so much by the total phosphorus content as by the condition of the phosphorus in the iron.

It will be noted that in some cases the steadite appears as little round particles, whereas in other cases it has the hook-like appearance seen in Fig. 7. We have found that the iron showing these hooks gives us the worst condition. The particular iron of Fig. 7 gave us more trouble than the iron of Fig. 5, for example. Of course, the photomicrograph of Fig. 5 does not show any steadite.

D. P. SPENCER:² I note a reference in the paper specifically to pig

² Metallurgist, Racine Steel Castings Co., Racine, Wis.

irons of high silicon and manganese content. Have the authors studied pig irons of low silicon content to determine whether they might attribute this trouble to the employment of certain ores, or whether it might result from higher blast-furnace temperatures in getting high-silicon pig? Is there a possibility that this trouble might result from the formation of double carbide in the pig iron? Could we expect to encounter this trouble in pig irons of lower silicon content?

C. F. JOSEPH: There is no question but that the same trouble might be encountered, but it may be caused by other factors. We have studied the blast furnace data; in fact, for about 15 or 20 heats we got complete data (more than are shown in Table 4) on how the blast furnace was run. We found that blast furnace practice varies a great deal, operation in most instances being rather crude.

However, we were unable to put our finger on anything wrong with the blast furnace operation that would cause this trouble, except with the ores. In one particular case an ore was used that was really an "off" ore—that is mentioned in paragraph 44. Of that particular ore only one per cent was used in the blast furnace burden. One per cent is a very small amount, and naturally one would not think it would give trouble; but it did.

This run was made with that particular ore as part of the burden for five weeks, and the following two weeks of the run the ore was taken off. Nothing else in the blast furnace practice was changed. The castings made from the pig iron from the early part of the run using the "off" ore, gave us a great deal of trouble; they were speckled badly. Castings made from the last part of the run, with that ore taken off, showed up well; they were excellent, with clean black fractures and just as fine grained as one could want.

Of course, this particular ore was an "off" ore, containing considerable titanium and phosphorus. In other cases, however, we have been able to trace back other ores which, when left off the burden, gave us better iron.

I am positive that the ores used in the blast furnace burden have much to do with any trouble that foundries may have with their castings, whether they use a 2 per cent silicon iron or an 8 per cent silicon iron. We have no data to show that the 2 per cent iron will give trouble, but when we made air-furnace malleable years ago, at times (infrequently) we ran into conditions that would give us rims, high shrinkage or other troubles, and by changing pig irons we naturally overcame some of those troubles. We did not attempt to find out why; we simply would change materials.

J. H. LANSING:² As a practical consideration, for many years most of us have used four or five cars of iron in making up a charge, having the thought that this practice would minimize the evil effect of any bad pig iron. Is it not possible for the authors to do the same in their process? Of course, I appreciate the fact that they use less pig iron, and it would be more difficult; or have they tried using a small percentage,

² Works Manager, Danville Malleable Iron Div., Allith-Prouty Co., Danville, Ill.

say, 25 per cent of the iron with the structure causing your difficulty, and using 75 per cent of other kinds?

C. F. JOSEPH: In paragraph 16 we cite a case where half good and half bad iron was used (the iron that gives us speckled castings we always call "bad" iron). We found that the castings even then came out speckled, but we did not use any less proportion of the bad iron to see if it still would give trouble.

If one went down to 6 or 4 or 2 per cent, probably the trouble would decrease; but I still believe that iron which showed up as did this particular bad iron, even if used in 1 or 2 per cent, eventually would give trouble. Of course, some of the pig irons do not show up as badly as others. The particular iron marked *B* in Fig. 7 probably would show a great deal less of the trouble than the irons marked *A*, *C* and *D*.

MEMBER: How much does the bad iron lower the elongation?

C. F. JOSEPH: We made some iron with good pig iron and the elongation ran about 4 per cent higher, on the average, than with the bad pig iron; that is, the good iron would give 16 per cent elongation, compared with 12 per cent for the bad iron.

W. P. PUTNAM: Does this condition as shown by the addition of alloying elements give the same characteristics as were obtained or observed by the use of the off-grade pig iron mentioned? Is the microstructure the same in both cases, whether the speckled condition was obtained by adding the alloy additions to the ladle or whether it came from the pig iron as originally melted?

C. F. JOSEPH: As to the microstructure obtained by the alloy additions, we made no photomicrographs of them; we looked at them visually and got the general idea of the structure in that way. Most of the alloys, except vanadium and chromium and tin, had no bad effect on the iron unless added in considerable quantities.

Titanium, in very small amounts, seemed to coarsen the structure badly. In fact, we used 0.005, 0.01 and up to 0.05 per cent, and each time we added 0.01 per cent we obtained bad coarsening. When the titanium is carried in the pig iron itself, we found that we could run a higher percentage, in some cases up to 0.02 per cent. This is mentioned in paragraph 39 of the paper. The presence of over 0.015 per cent titanium caused the iron to have a coarse-grained fracture and pearlitic rims.

W. P. PUTNAM: In one case you attributed the trouble to steadite, and in another case to something else.

C. F. JOSEPH: I believe there are many reasons for this structure, but lately we have had the impression that the most important reason is possibly the formation of steadite in the pig iron, because the iron than has no steadite gives no trouble at all, whereas the iron containing the steadite gives a great deal of trouble.

W. P. PUTNAM: That brings up another point. If pig iron gives

⁴ Detroit Testing Laboratory, Detroit.

these results with steadite, could you not add the alloy elements to good iron without steadite in it?

C. F. JOSEPH: The elements were added to good iron and the paper shows the results obtained, from pig iron that had no steadite in it.

D. P. SPENCER: Were you able to identify, in the finished product, any of the inherent characteristics of the pig iron? Were you able to see any steadite in the finished product?

C. F. JOSEPH: We have examined many pieces under the microscope in both the hard and the annealed state, and in both conditions we could observe no steadite. However, one should be able to see the ternary alloy. As I understand it, the phosphorus does not form as steadite in a white iron. The iron must be mottled in order to have this steadite form.

We have used as high as 1100 to 2200 magnifications, and we see the ternary alloy in pig iron made from the pig iron containing the steadite. This seemed to show that this material continues through the cupola into the electric furnace until the casting is poured, except that it assumes a different form. If we run this particular pig iron for one, two or three days, we seem to see more of the ternary alloy under the microscope in the hard iron.

I have been trying to find out much more about the formation of the ternary alloy. It is something that has come up recently, and I imagine that considerable work will be done on it in the near future. In fact, we are doing something on it every day, trying to find out why the ternary alloy does not break down more easily.

L. J. KELLY:⁵ We operate an open-hearth furnace with a Fifield oven, using about 25 or 30 per cent pig iron, and we have not experienced the trouble noted in the paper. At no time have we found anything like it. Consequently, I wonder if the trouble may not be in the melting or annealing practice.

C. F. JOSEPH: It has been proven that that is not the case, because we do not change our practice at all. One day we may start out with the iron that gives us no trouble and run that iron until, say, 10:00 a. m. Then we may change over to the pig iron that gives us trouble and pour square test bars, 1 in. square by 8 in. long, every half hour all day. That gives us 20 test bars, numbered consecutively.

Suppose that bar No. 6 is poured at 10 o'clock. The first six bars will show a beautiful black, velvety structure; bar No. 7 will show a good structure but not as good as No. 6; bar No. 8, made from the bad iron, will show a tendency to be a little coarser; and bars Nos. 9, 10, 11, 12 and on up to 20 probably will all show the coarse structure, and still our practice has been exactly the same all day long.

We have tried this out dozens of times. We have taken good iron, or bad iron, started up in the morning and then changed some time during the day to the other iron, and the breaking point will be very close; one can see the breaking point where the iron has been changed,

⁵ Superintendent, Fort Pitt Malleable Iron Co., Pittsburgh.

within one or two test bars. We maintain fairly good operation and try to run uniformly all day long. That check has been made so many times that we are absolutely convinced it is the pig iron that gives us the trouble.

A. L. BOEGEHOLD: Mr. Kelly mentioned using from 25 to 35 per cent of pig iron in the charge. Presumably, that is a low-silicon pig iron.

L. J. KELLY: About 2 to 2.5 per cent silicon.

A. L. BOEGEHOLD: We are dealing here with an entirely different grade of pig iron, one running 9 or 10 per cent silicon and 2.5 per cent manganese. Possibly we have a critical condition with that amount of silicon and manganese in the pig iron that throws the phosphorus out of solution and produces steadite with as little as 0.15 to 0.30 per cent phosphorus present, whereas with the low-silicon or ordinary malleable pig iron that amount of phosphorus never would cause formation of steadite.

The Open-Hearth Furnace as a Means of Recovering Cast Iron from Borings*

By T. L. JOSEPH† AND C. E. WOOD,** MINNEAPOLIS

Abstract

Because of the difference in current prices of pig iron and cast-iron borings, the use of borings offers a substantial financial inducement to plants operating foundries and machine shops from which borings segregated as to composition can be obtained. The results of the experiments detailed in the paper show that cast-iron borings can be melted in an open-hearth furnace, provided they are properly protected before and after melting with slag and small coke. The weight of the metal recovered will be about 90 per cent of the weight of the borings charged. Under proper supervision it seems feasible to cast the metal direct from the open-hearth furnace, inasmuch as the iron can be superheated if desired, and chemical specifications met. As an alternative, the metal from the open-hearth furnace can be pigged and subsequently melted in the cupola.

1. The recent decline in scrap prices has been greater than the decline in prices of pig iron. Current prices of pig iron and cast-iron borings offer a substantial financial inducement to fabricating plants that operate foundries and machine shops from which borings segregated as to composition can be obtained. This

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NOTE: This paper was presented and discussed before one of the gray iron sessions at the 1932 convention of the American Foundrymen's Association.

Table 1

PRICES OF NO. 2 FOUNDRY IRON AND CAST-IRON BORINGS

Location.	Price per Ton, Dollars	
	No. 2 Foundry Iron.	Cast-Iron Borings.
Pittsburgh, delivered	17.13 to 18.13	6.75 to 7.00
Chicago, furnace	16.50	3.00 to 3.50
Cleveland, local delv	16.00	4.25 to 4.75
Buffalo, local delv.	16.00	6.00 to 6.25
Boston:		
Buffalo, all rail	{ 19.91 to 20.41 }	1.05 to 1.55
Alabama, dock delv	{ 16.50 to 16.75 }	
St. Louis	14.42	5.00 to 5.50
Cincinnati ..	13.82	3.25 to 3.75
Birmingham	12.00	3.00 to 3.50
Philadelphia	15.26 to 15.76	3.00 to 3.50
New York, at docks.....	15.50	1.50 to 2.00

NOTE: Quotations from *Steel*, vol. 90, no. 3, Jan. 18, 1932, pp. 50, 52.

is particularly true of plants located at remote distances from blast furnaces.

2. Table 1 shows a difference of from \$9 to \$15 between recent quotations on No. 2 foundry iron and on cast-iron borings. Normally, the difference in the price of these materials would be less for most locations than that shown in Table 1. However, under normal conditions there is a large price margin in many localities for recovering metal satisfactory in composition but unsuitable in physical form for melting in the cupola.

3. It is well known that borings can be melted satisfactorily in an electric furnace. Except for locations where electric current is cheap, costs for open-hearth melting would be cheaper. Flexibility in operation and greater ease in establishing a reducing atmosphere over the bath are recognized as advantages favoring electric-furnace melting.

4. Normally, open-hearth conditions are strongly oxidizing. However, during the development of a method for producing ferro-manganese from manganiferous iron ores, the authors found that reducing conditions could be established over an open-hearth bath by covering it with a layer of small coke several inches deep.

5. Fig. 1 shows that during a three-hour period under a layer of pea coke at a temperature of 1575 degs. Cent. (2867 degs. Fahr.) the ferrous oxide in a high-manganese and comparatively viscous slag was reduced from 67 to 4.5 per cent, and

the phosphorus from 1.6 to 0.1 per cent. The increase of manganese in the metal is another indication of reducing conditions.

Borings Melted in Open-Hearth Furnace

6. In view of similar results on a large number of heats, it seemed feasible to melt cast-iron borings in an open-hearth furnace, if the borings were properly protected from the flames by coke and slag. Two melts of borings were made in order to get sufficient metal to cast an iron box needed as a slag ladle.

7. Data on these melts are reported because they indicate that under proper conditions cast-iron borings can be readily melted in an open-hearth furnace and cast directly, or pigged

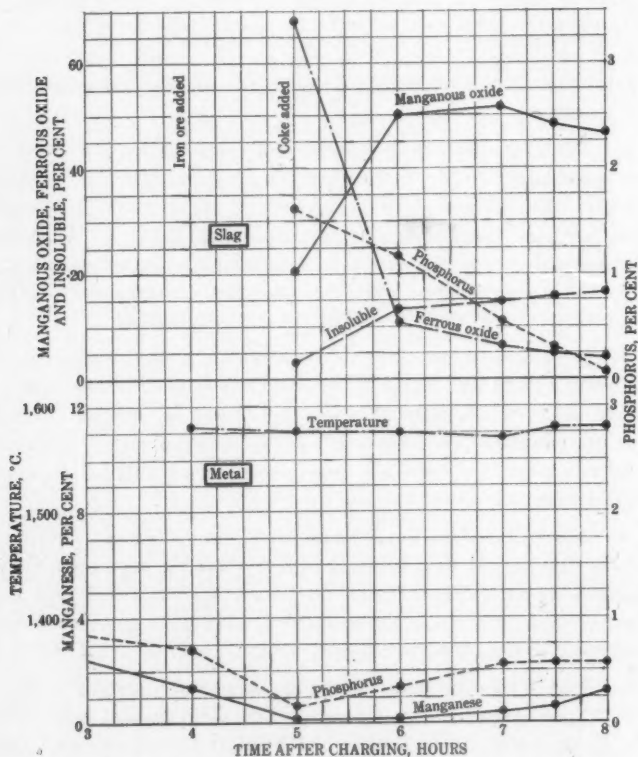


FIG. 1—CHANGES IN COMPOSITION OF SLAG AND METAL IN HEAT NO. 418.

Table 2
COMPOSITION OF SLAG AND BORINGS BEFORE AND AFTER MELTING

	Metal					Slag				
	Si	S	Mn	P	C	CaO	MgO	SiO ₂	Al ₂ O ₃	FeO
Before melting	1.37	0.084	0.55	0.23	2.92	20.0	24.0	25.0	22.0	3.5
After melting	1.33	0.067	0.64	0.22	2.86	....	....	....	....	....
<i>Melt No. 2</i>										
Before melting	1.76	0.080	0.55	0.22	2.95	32.0	14.0	20.0	26.0	3.5
After melting	0.76	0.011	0.30	0.20	2.88	....	....	....	....	....

and remelted in a cupola. The analyses of the borings used, of the metal produced, and of the slag are given in Table 2.

8. In melt No. 1, the borings were charged and covered with consecutive layers of high-alumina slag and coke. Coke was added from time to time to keep the bath well covered. As shown in Table 2, a small loss of silicon and sulphur occurred in melting. The change in manganese, phosphorus and carbon was slight. The metal was gray and close grained, but it machined readily.

9. To observe the effect on sulphur elimination, the borings for the second melt were coated with a lime wash and allowed to dry before charging. In place of a batch-type operation as in melt No. 1, the borings were charged at intervals and part of the metal was tapped as it accumulated. The average analysis of the metal tapped shows a loss of about 1 per cent of silicon, 0.069 per cent of sulphur, 0.25 per cent of manganese, and a slight decrease in carbon and phosphorus.

10. These two melts show that under some conditions a large part of the sulphur can be eliminated. Whether this can be accomplished without a substantial loss of silicon was not determined.

11. The silicon could be built up by the addition of ferro-silicon, but it would be more economical to melt under conditions that would give the smallest loss of silicon, even though the reduction in sulphur were small. However, if low-sulphur metal were wanted, it could be obtained from borings.

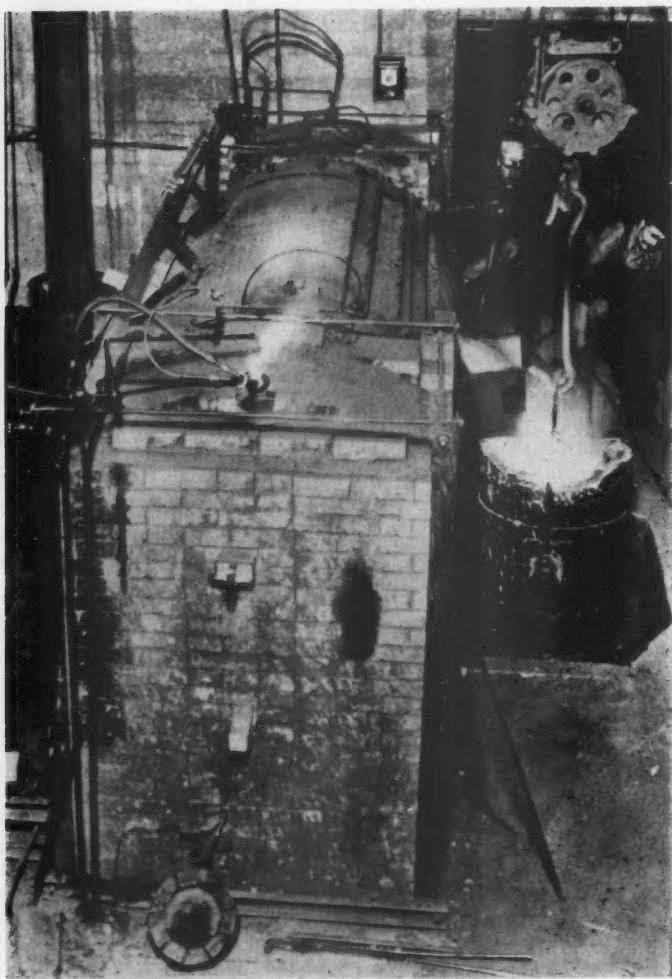


FIG. 2—HALF-TON TILTING OPEN-HEARTH FURNACE.

Coke Required

12. Data from the small furnace indicate that about 200 lbs. of small coke would be required per ton of metal produced.

Recovery

13. In melts Nos. 1 and 2, a total of 1800 lbs. of metal was recovered from 2000 lbs. of borings, indicating a possible recovery of about 90 per cent from clean borings free from rust.

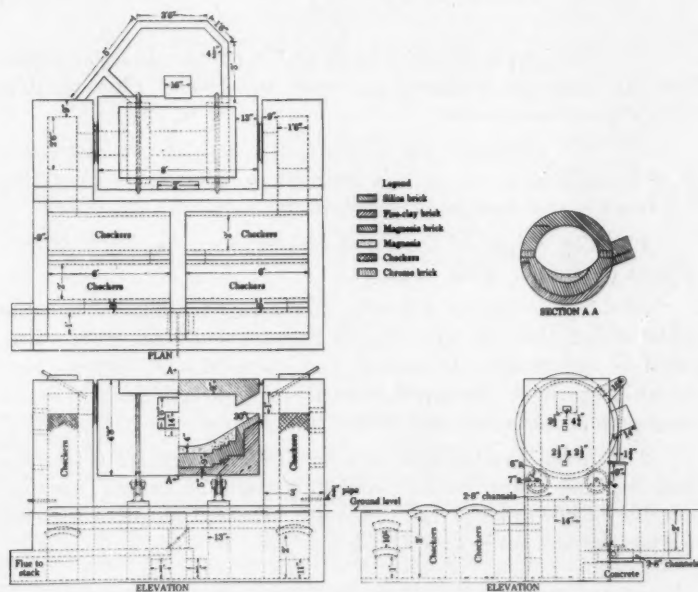


FIG. 3—PLAN AND ELEVATION OF U. S. BUREAU OF MINES EXPERIMENTAL
OPEN-HEARTH FURNACE.

Rate of Melting

14. The melting rate was about 2000 lbs. of borings in 4 hours. By arranging to charge through the roof, it should be possible to melt between 6 and 7 tons per 24 hours.

15. A furnace about 4 feet longer than the one shown in Figs. 2 and 3 would be more satisfactory, as this would permit better flame propagation and would require less fuel. The esti-

mated melting capacity of such a furnace would be 10 to 12 tons of borings per 24 hours. Larger furnaces could be built as warranted by the plant production of borings.

Fuel Requirements

16. The furnace used in these tests required about 8 gallons of fuel oil per hour, which would be approximately 30 gallons per ton of borings. With a larger furnace, the oil required per ton probably could be reduced to 25 gallons.

SUMMARY

17. Cast-iron borings can be melted in an open-hearth furnace provided they are properly protected before and after melting with slag and small coke.

18. The operation can be manipulated so that a small loss in silicon will occur; or, if it is desirable to eliminate sulphur, this can be done at a sacrifice of silicon in the metal.

19. The weight of the metal recovered will be about 90 per cent of the weight of the borings.

20. Under proper supervision it seems feasible to cast the metal direct from the open-hearth furnace, inasmuch as the iron could be superheated, if desired, and chemical specifications met. As an alternative, the metal from the open-hearth furnace could be pigged and subsequently melted in a cupola.

21. In the case of fabricating plants that operate a foundry and machine shops, borings probably could be melted for one-quarter to one-third of the difference between the price received for borings and the price paid for pig iron.

Sand Control in the Steel Foundry

By A. V. LEUN,* BETHLEHEM, PA.

Abstract

The author describes methods of sand control which might be adopted in any steel foundry making both green and dry sand castings weighing from one pound to 100 tons. The discussion is divided into two parts, the first dealing with control of incoming raw materials, the second with control of the materials in use. Testing equipment used is described, the tests being for green tensile strength, dry tensile strength, permeability, fineness, and classification of various clays and sands with respect to their resistance to metallic penetration by hot metal. Specifications for sands and binding materials are discussed, as are mold washes. In controlling the materials in use, checks are made on the various properties, such as dry and green strength, permeability, and moisture content. Where molds are to be finished at once, a different binder is used than when the mold is left for some time before finishing. Core room control concludes the author's presentation.

1. Over the past number of years much has been said and done in reference to properly controlling the various phases or uses to which sand is put in the production of steel castings. In many cases the method adopted to control sand has not been the most desirable for the particular shop involved. Therefore, in this discussion we will describe methods of sand control which might be adopted in any steel foundry making both green and dry sand castings, the castings weighing from one pound to 100 tons.

2. In discussing the problem it will be best to divide the application of control into that pertaining to the incoming raw materials, and, secondly, to the use of these materials in the foundry. However, before describing the handling of incoming materials, it would be in order to enumerate and in some cases describe the types of testing machines employed for such control.

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NOTE: This paper was presented and discussed before one of the courses on sand control at the 1932 convention of the American Foundrymen's Association.

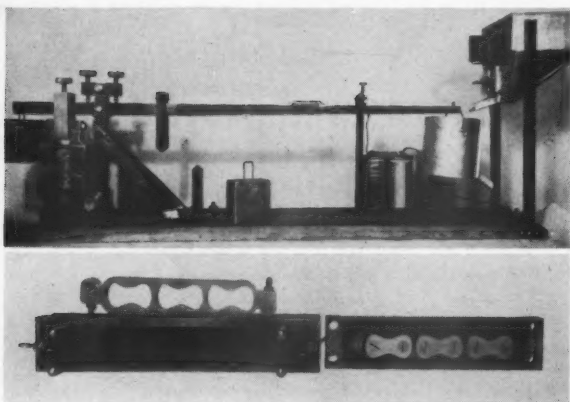


FIG. 1.—TOP: APPARATUS FOR DETERMINING GREEN STRENGTH OF SAND IN TENSION. AT LEFT, GRUBB TENSION CYLINDER CONNECTED BY RECEPTACLE AT CENTER WHICH RECEIVES SHOT FROM HOPPER AT RIGHT. HOPPER CONTROLLED ELECTRICALLY BY BREAKER MECHANISM GIVING DIRECT READINGS ON SCALE. BREAKER MECHANISM PROVIDES AN AUTOMATIC SHUT-OFF, ELIMINATING THE HUMAN ELEMENT FACTOR.

FIG. 2.—BOTTOM: APPARATUS FOR DETERMINING STRENGTH OF SAND IN TENSION WITH SAME TYPE OF BREAKER MECHANISM AS IN FIG. 1. SPRING IS USED HERE TO TAKE CARE OF DEFLECTION OF THE BEAM. IN CASE OF WEAK SAND, BUCKET IS HOOKED ON MIDDLE OF BEAM AND FED BY HAND. NORMAL RATIO FROM TIP OF BEAM TO TESTING POINT IS 1:10. STANDARD BRIQUET MOLD IS EMPLOYED, GIVING ONE SQUARE INCH AT SMALLEST CROSS-SECTION OF THE BRIQUET.

TESTING APPARATUS

Tension Test—Green Strength.

3. It has been the experience of the writer that the most sensitive and accurate test for green strength in sand is the tension test. This test accordingly is employed in preference to other methods now in vogue. A picture of the apparatus used in this test is shown in Fig. 1.

Tension Test—Dry Strength.

4. For determining dry strength, which is the paramount property in dry-sand casting, an apparatus pictured in Fig. 2 is employed. In this test briquets are broken. The briquets are made by using the rammer formerly employed in ramming the sand for the bar test, to ram the sand into a specially constructed 3-specimen mold, shown in Fig. 3. These three briquets then are

dried at a predetermined temperature, cooled, and broken in the apparatus, which is electrically controlled.

5. In some cases the dye adsorption test is employed, especially on clays.

6. For determining the openness of the sand, the standard A. F. A. test for permeability is used.

Moisture Test.

7. The moisture content is determined by drying the sand in an electric oven, weighing before and after.

Grain Size Test.

8. Screen tests are made by using the Ro-Tap apparatus in conjunction with a set of screens of sizes to fit the material tested.

Penetration of Metal Test.

9. The last and one of the most important tests is that used for classifying various clays and sands with respect to their resistance to metallic penetration by the hot metal. This test is carried out by ramming the refractory to be tested into an open mold $6 \times 6 \times 8$ in. deep around a pattern $3 \times 3 \times 6$ in. No wash or other facing is applied to the mold before being dried. After

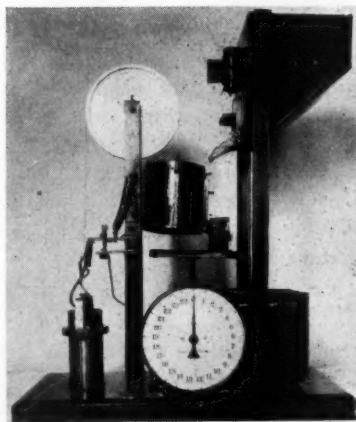


FIG. 3—SPECIAL 3-SPECIMEN MOLD FOR RAMMING BRIQUETS FOR DRY-STRENGTH TEST.

being dried, the mold is poured with steel at a temperature of approximately 2650 degs. Fahr. When it has cooled, the casting is removed and examined for signs of sand burning on.

10. If a new sand or clay is under consideration, this test may be run through three times on the same sand, determining by test the loss of strength as well as the change in permeability after each burn. Remarkably interesting results often are obtained in regard to the durability of various sands.

RAW MATERIALS AND SPECIFICATIONS

11. The materials that go into the making of molds, cores, etc., may be listed as follows: Sand, both strong and sharp; binders, such as clay, corn flour, oils, glutrines, etc.; and silica flour. It stands to reason that, by maintaining a reasonable and yet enforceable specification on the various materials listed above, we will be assured of a constant quality in the various materials when used in the foundry. This removes the factor of uncertainty as to raw materials when they are employed in preparing molds or cores.

Dry-Sand Castings.

12. In making our dry-sand castings a naturally-bonded semi-strong sand is used. This material comes from New Jersey and is maintained very uniform for a natural material. It possesses much greater dry strength than does a synthetic sand with an equivalent amount of clay.

13. To keep this product uniform, specifications are placed on it in regard to the percentage of coarse grains. A minimum permeability of 75 is held, and a dry strength of 8 lbs. per sq. in. is required when rammed up, while containing 7 per cent moisture, and dried at 750 degs. Fahr. for one hour. This latter specification is the most important, as it assures firm molds when dried and a minimum of cutting when they are poured.

Green-Sand Castings.

14. For green-sand casting a sharp sand is employed. It is purchased on screen analysis and on its freedom from impurities such as clay, strippings, etc. It would be useless to give a screen analysis as best suited for all green-sand casting. Preferably, however, it should be concentrated on one or two screens

with a minimum of coarse grains and also a minimum of fine grains.

Core Oils and Binders.

15. In testing core oils, corn flour, resin binders, bentonites, etc., the most rapid and yet accurate method is to mix the binder in a specified proportion with a sand such as Williamstown Junction, Manumuskin, or Ottawa washed sand. Any suitable washed sand will suffice, all that is necessary being to maintain the material constant in screen analysis so that it can always be used as the base in testing the various binders.

16. The test employed in our laboratory is to mix 4 ozs. of the binder with 15 lbs. of sand and 5 per cent water. This mixture is mulled in a laboratory muller, or it can be worked up by hand, for five minutes. It then is rammed up into briquets, baked at the proper temperature, depending on the use to which it is to be put, cooled, and tested for dry strength by breaking.

17. The resulting dry strength, when divided into the cost of the binder per 100 lbs., will give the cost of the binder per pound of dry strength, and will be an index of the economy of the binder if employed. This method is adapted to our foundries and has given very satisfactory results when comparing different binders, as well as giving us a yardstick by which to test incoming shipments of those binders adopted for use.

Clay for Bonding Sand.

18. Clay for bonding molding sand must possess certain properties such as high dry strength and high green strength, and must be ground sufficiently fine to be economical in use.

19. To determine the suitability of a new clay for foundry use, it first is mulled with Williamstown Junction sand in the ratio of 15 per cent clay to 85 per cent sand. Enough water is added to give the mix sufficient plasticity. This sand then is rammed into the mold described previously. The mold is then dried and poured, the casting being studied as to its appearance. This test will differentiate rapidly between good and bad clays for foundry use.

20. The accompanying Fig. 4 shows the test castings resulting from testing three well-known clays. The difference between the three surfaces is very pronounced. It shows the great

variation between clays as to "burning on."

21. It has been our experience that the fusion point of the clay does not affect the appearance of the castings, provided, however, that the clay is not too full of undesirable fluxes. Also, it appears that the greater the shrinkage of the clay, the cleaner will be the resulting castings, possibly due to the pulling away of the mold from the metal face of the casting after pouring.

22. The plasticity of the clay or its ability to bond molding sand will be shown by its dye adsorption, which is an indication of the colloidal qualities of the clay. The dry strength developed by the clay when used in conjunction with sand and baked at a certain temperature will be indicated by the dry strength of the clay itself, dried at the same temperature as it will be subjected to in the foundry. This dry strength of the clay is best determined by ramming the clay into briquets, drying at the proper temperature, cooling, and breaking.

Specifications for Clay.

23. A specification for clay to be used in molding and which is in effect for our steel foundry, is as follows:

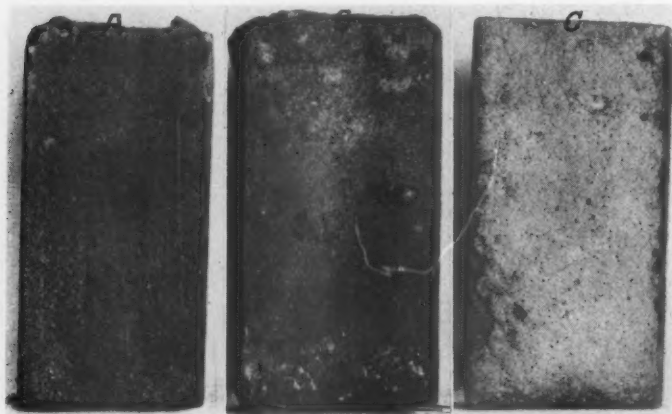


FIG. 4—TEST CASTINGS SHOWING BURNING-ON EFFECTS OF VARIOUS CLAYS. A: WEST VIRGINIA CLAY; FUSION TEMPERATURE, 2840 DEGS. FAHR.; DRY STRENGTH, 40 LBS. PER SQ. IN.; DYE ADSORPTION, 1950. B: COMMONLY USED OHIO CLAY; FUSION TEMPERATURE, 2960 DEGS. FAHR.; DRY STRENGTH, 25 LBS. PER SQ. IN.; DYE ADSORPTION, 1500. C: PENNSYLVANIA CLAY WIDELY USED IN STEEL FOUNDRIES; FUSION TEMPERATURE, 3040 DEGS. FAHR.; DRY STRENGTH, 20 LBS. PER SQ. IN.; DYE ADSORPTION, 1450.

"The clay is to be finely ground. When worked up into plastic form, molded into standard briquets and baked at 600 degs. Fahr., the dry strength in tension must be not less than 40 lbs. per sq. in. The dye adsorption must not be less than 1800. The clay must not vitrify at a temperature less than 2300 degs. Fahr."

24. By adoption of the proper clay, possessing good cleaning qualities, high dry strength and high plasticity, a minimum of clay will have to be used to give the necessary green and dry strengths to the sand. This will aid in keeping the sand from "closing up" due to continued use and accumulation of burned-out clay, etc.

25. Many clays lose their dry strength at temperatures as low as 500 degs. Fahr. These clays, while giving clean castings, necessitate the use of a greater amount of clay to get the desired strength. This is neither economical nor good practice. A clay of this type is the Welch Mountain clay, which is highly siliceous.

Silica Flour.

26. Silica flour has two uses in the foundry. It is used in addition to molding sand and core sand to present a tighter sand body to the hot metal where heavy sections are encountered and penetration is to be kept to a minimum. It is also the basis of the mold wash used extensively on dry-sand molds to close the surface to the molten steel. For the first use it is not necessary that the flour be as fine as when it is to be used for mold wash. Many foundries use the so-called 140-mesh silica flour for this job. A satisfactory specification for this grade of silica flour is that 95 per cent pass the 200-mesh sieve.

Mold Washes.

27. For mold wash, air-floated silica flour is commonly employed. This grade of silica flour allows for a lesser proportion of deflocculant or other material for maintaining it in suspension. It also greatly decreases the settling of the material if forced to stand overnight.

28. The mold washes used in various foundries differ. Some plants add bentonite and molasses, others add a corn flour, glutrine, etc. However, a small amount of bentonite, together with a small proportion of a corn flour, when added to the silica

flour and water will give a wash possessing sufficient suspension qualities and sufficient tenacity so that it cannot be rubbed off the mold surfaces after being baked.

29. The best method of controlling silica mold wash is to maintain it at a constant specific gravity. This can be done easily by use of a hydrometer, suspending it into the wash and noting the reading.

30. A good range of specific gravity in which to hold the wash for best results is between 1.350 and 1.420. If the wash is allowed to get too thin it will not coat the mold sufficiently, while if it is allowed to become too thick it will crack off the molds on which it has been applied either before or during pouring of the steel. The best wash will not prevent metallic penetration, however, if the sand is not refractory enough, if the mold is improperly made, or if the metal is poured too hot or too rapidly.

PROCEDURES IN SAND CONTROL

31. Having a close control over the incoming materials, attention must be paid to the proper mixing and use of these materials in preparing the various molding and core sands. The procedure adopted for controlling the sand in a foundry must be one best suited to the type of work made and one as simplified as possible.

Dry-Sand Strength.

32. In a steel foundry making castings in dry sand the most important property to control with reference to the sand is the dry strength. This dry strength depends to a great extent on the amount and the type of binder added or in the sand. It has been found that for all classes of work the dry-sand strength should not be less than 10 lbs. per sq. in. In most cases it usually is as high as 15 to 20 lbs. per sq. in. Where the dry strength falls below this figure the chances for cutting, washing and dirty castings are greatly increased.

33. Maintaining this high dry strength gives strong molds after drying and allows for easier core setting, etc. This dry strength is determined by ramming the sand sample into briquets, as described before. These briquets are baked for one hour at 750 degs. Fahr., cooled, and broken on the dry-strength appara-

tus. Additions of silica flour decrease the dry strength of the sand but recompense for this reduction by giving a tighter, smoother and finer facing. The addition of 30 per cent of silica flour will decrease the dry strength from 20 lbs. to 15 lbs., or in that ratio.

34. When close control is held on incoming foundry refractories and the same mix of materials is maintained, it is not necessary to determine the dry strength on all batches of sand mulled or otherwise mixed. It is originally necessary to set up a mix for dry-sand molding, however, having the proper dry strength as outlined above.

35. In the steel foundry of the Bethlehem Steel Co. at Bethlehem, Pa., we do not check all batches of sand. Only occasional mixes are tested. It has been found that by the control exercised over the raw materials entering and by the maintenance of constant mixes in the shop, a satisfactory dry strength is maintained easily over a long period of time. This has been proven in actual test.

Moisture Control of Dry Sand.

36. The dry strength developed is dependent not only on the sand and binder but also on the amount of water present and the intensity of mixing. As the water content does not have to be closely controlled, it is comparatively simple to train an operator to keep the sand within reasonable limits by feel.

37. The average water content of sand prepared for dry-sand molding generally averages between 7 and 8 per cent. To go below 7 per cent is to cause a reduction in dry strength, dependent on the deficiency of water. The dry strength of sand containing 6 per cent water generally runs about 25 per cent less than that containing 7 per cent water. The wetter the sand, up to about 9 per cent water content, the greater the dry strength. This high water content, however, namely, above 8 per cent, makes the sand less workable, causing increased difficulties in drying and adding to the drying cost.

Green-Sand Strength.

38. The green strength maintained on such sand is dependent on the dry strength aimed at. When the dry strength is 15 to 20 lbs. per sq. in., the briquets being baked at 750 degs.

Fahr., the green strength will average between 1.75 and 2.5 lbs. per sq in. in tension. Generally it is not necessary to bother with the green strength because the sand, to contain a high dry strength, always will have sufficient plasticity to make it workable.

Green-Sand Permeability.

39. Permeability, while of paramount importance in green-sand molding, plays a minor part in dry-sand casting. It is true that the more open the backing and facing sands, the more easily and quickly will the molds dry in the oven; but it is also true that the heavier the metal section, the more compact and dense must the facing sand be. This is brought about by the addition of silica flour in amounts ranging from 10 to 50 per cent. In such cases, the permeability decreases rapidly.

40. To maintain an open backing sand is an advantage. This requires special equipment for removing the "fines." This apparatus is far more important when green-sand molding is in the majority.

Dry vs. Green Permeability.

41. In the average shop specializing in dry-sand jobbing work, the permeability of the sand usually will run from 10 on heavy work, to 55 to 100 on light-medium castings. When the sand is dried, however, this permeability increases in all cases, often as high as 100 per cent over the permeability of the sand when in the green state.

42. For green-sand casting, careful watch must be kept over the permeability, moisture content and green and dry strengths of the sand. The higher the permeability, provided the green and dry strengths are maintained satisfactorily, the sounder will be the castings produced.

43. The maximum permeability obtained is dependent on the sand employed and the binder added to it. The maximum permeability maintained in practice is dependent on the degree of cleaning the old sand receives and on the surfaces of the castings produced. Where facing sand is employed, its permeability is limited by the openness of the backing sand, as it is useless to maintain an open facing if the backing material is of much lower permeability.

44. For the individual shop the most desirable permeability is best arrived at by keeping it as high as possible, yet getting clean and moderately smooth castings. Provided the refractoriness of the sand is right, rough castings mean too open facing sand, which must be corrected either by adopting a different base sand or by blending a finer sand with the one in use.

Strength and Moisture Control.

45. For green-sand casting a sharp sand generally is employed, to which is added sufficient corn flour, bentonite, clay, etc., to produce the necessary green and dry strengths. It is necessary that the water added be controlled very closely.

46. The best moisture content for a particular shop making green-sand castings depends on the base sand employed as well as on the binders added. It is best determined by test and observation. In most cases, however, the water contained in the prepared sand will average close to 5 per cent. If the moisture content goes much below that set for best results, the resistance of the sand to vibration and (when being poured) to erosion, will be greatly decreased. If, on the other hand, the moisture is too high, "cold shorts," "blows," and scabby castings may result.

47. A simple method of testing for the water content in the sand is to dry out a known weight of it at 212 degs. Fahr., weighing after drying, and determining the moisture content by the loss of weight.

Checking Sand Samples.

48. The samples taken from sands prepared in the shop should also be tested for permeability, green strength and dry strength. These tests take about five minutes each, not counting the time taken for drying out the briquets for the dry strength test—this time is one hour. These three variables are seldom out of line if a constant mix is maintained. The water content occasionally falls outside the limits set and the sand must be corrected before being used.

49. In one shop the sand and binders are mulled to properly mix them and the mixture then is tempered. It is then placed in large steel boxes, holding about one ton of sand each. This sand, not being required for use for several hours, is tested as outlined above. If it meets the specifications set up for it, it

is passed on for use. However, if the sand is too wet, etc., it is remixed to remedy the condition, before going to the molding floor. The tests described are performed as outlined at the beginning of this paper, with the apparatus shown in Fig. 1.

Green-Sand Facing.

50. Depending on the use to which the green-sand facing is to be put, the proper binders are added to it. If the molds are to be finished soon after being rammed, the use of a corn binder for producing green strength, in conjunction with a clay or bentonite, is satisfactory. However, if the molds must remain open for any length of time before being "finished," the corn flour will have dried and the sand will not take water appreciably; this makes the "finishing" very difficult.

Table I

Type of Work.	H ₂ O	Permeability	Grn. Stgth. in Tension, lbs.	Dry Stgth. in Tension—400 degs. Fahr., lbs.
Light-simple steel.....	5.1	100	1.0	9
Medium-mang. steel.....	5.0	300	1.75	22
Medium-heavy, simple steel....	4.8	150	1.50	13

51. Under such circumstances, for proper sand control, the choice of a dextrin to replace the other type of corn flour is necessary. This retains its moisture much longer than will the corn binders for obtaining green-sand strength. Therefore, before mixing the sand the operator should first find out how or when the sand is to be used, adding the proper binders accordingly.

Dry Strength of Green Sand Important.

52. In green-sand casting, as in dry-sand work, the dry strength of the sand is very important. If we maintain sufficient green strength in the sand to make it workable, we generally will have the proper dry strength. From comparisons made in the foundry, a minimum dry strength of 7 lbs. per sq. in. is necessary for clean castings. The test briquets are baked at 400 degs. Fahr. Table I tabulates several actual tests made on sand mixes used successfully for green-sand casting.

CORE-ROOM SAND CONTROL

53. The control exercised in the core room is best divided into (a) heavy and (b) light-medium steel castings.

Cores for Heavy Sections.

54. When making cores for castings having heavy sections or where the core will receive considerable punishment from the hot metal, a refractory, dense and fairly hard facing, for the core must be employed. Such a core-sand facing generally will run between 30 and 45 lbs. per sq. in. dry strength, the briquets being baked at 550 degs. Fahr. Its permeability will be low, due to silica flour being added.

55. The backing sand for this strong sand is open but weak, testing about 3 lbs. per sq. in. dry strength. Control for this class of core sand is best carried out by careful choice of the core binder, together with the percentage used and the proportion of silica flour added to the sand.

56. Since cleaning is paramount, the use of old sand, especially that containing any quantity of "fines," often is not economical. Close touch should be kept with the cleaning floor and changes made in the core sand to get the best and easiest cleaning mix. Several mixes used with good results on heavy and medium heavy castings are as follows:

Medium-heavy castings—	20 parts strong sand—new
	4 parts silica flour
	1 part resin binder
Heavy castings—	10 parts strong sand—new sand
	12 parts silica flour

Cores for Light-Section Work.

57. For light or medium weight castings, where the metal sections are not heavy enough to resist cracking on cooling (due to the failure of the surrounded cores to give or lose enough of their strength to weaken them), a different type of core sand must be employed. For this class of core sand many foundries employ oil sand, while others use the regular core-sand mix minus the silica flour, which always tends to make the core more resistant to deterioration under heat. In this latter case the dry strength of the core sand when baked at 550 degs. Fahr. will average between 15 and 25 lbs. per sq. in.

58. In the case of oil sand, its dry strength baked at 400 degs. Fahr. will be between 40 and 65 lbs. per sq. in. The ratio of oil to sharp sand for satisfactory cores depends to a great extent on the type of oil used, *i. e.*, the quantity of linseed oil in the core oil employed.

59. It is seldom necessary to add silica flour to oil sand for metal thicknesses less than 2 to 2½ inches. To exercise control in this class of core sand, one must first determine the most economical oil to employ, set up a specification on it and enforce it on future shipments. Such a method was described under binders on an earlier page. The mixing of the sharp sand, oil and additional binder to give dry strength should be controlled with respect to the percentages of oil and binder added and the percentages of water employed. Here, again, the dry strength is the important test to use as a guide.

Mixing Practice.

60. When mixing sand, oil, corn flour and water it is best practice to mix the sand, oil and water first and then, when the oil is thoroughly mixed in the sand, to add the corn flour. This will develop the green strength more rapidly than any other order of mixing. Many foundries employ dextrine as the binder for cores. The choice of binder is determined on the basis of the one best suited to the shop conditions and most economical.

Test for Core Resistance to Contracting Casting.

61. A good test to determine the ability of a core mix to sufficiently break down so as to relieve strains in a casting, and one which has worked out satisfactorily in connection with core room practice, is as follows: Ram the core sand into briquets in the regular way. Make two sets of briquets. Bake one set at 400 degs. Fahr. and the other set at 1200 degs. Fahr. for 15 minutes. Allow these briquets to cool, then break them in the dry-strength apparatus. Care must be taken not to break the cores by handling in placing them in the test machine, particularly those baked at 1200 degrees. If they are broken, their strength can be taken as less than one pound per square inch.

62. The set baked at 400 degs. Fahr. will show the strength of the cores when placed in the molds preliminary to pouring. The set baked at 1200 degs. Fahr. will show the loss in strength

that may be expected in the core after being surrounded by the molten metal. If this strength is still over three pounds, trouble may be expected in cracked castings. This test is only meant for application on light-section work, or where the "setting up" of the steel is so rapid that very little time is allowed for destruction of the core binder.

SUMMARY

63. In concluding and summarizing the contents of this paper, it would be in order to tabulate the most practical tests to employ under various conditions met in the steel foundry, as follows:

A—Raw materials entering the foundry.

- (1) Sand, naturally bonded.
 - (a) Dry strength.
 - (b) Permeability.
 - (c) Screen analysis in respect to the coarser or fine grains.
- (2) Sand, sharp.
 - (a) Screen analysis.
 - (b) Cleanliness and freedom from impurities.
- (3) Binders—corn flour, oils, bentonite, etc.
 - (a) Dry strength, cost per pound of dry strength developed using standard mix.
 - (b) Green strength developed.
- (4) Silica flour.
 - (a) Screen analysis of regular and air-floated.
 - (b) Suspension qualities of air-floated.
- (5) Clays for bonding molding sands.
 - (a) Screen analysis.
 - (b) Dye adsorption.
 - (c) Dry strength of material.
 - (d) Ability to resist burning on the casting.

B—Foundry control.

- (1) Dry-sand casting.
 - (a) Dry-sand strength of prepared sand.
- (2) Green-sand casting.
 - (a) Moisture content.

- (b) Permeability.
 - (c) Green strength of sand in tension.
 - (d) Dry strength in tension.
- (3) Core sand.
- (a) Dry strength baked at temperature at which cores are baked.
 - (b) Dry strength baked at 1200 degs. Fahr. for 15 minutes.
 - (c) Green strength.
- (4) Mold wash.
- (a) Specific gravity of wash.
 - (b) Rate of settling of wash.

Casting Properties of Nickel Bronzes

By N. B. PILLING* AND T. E. KIHLGREN,* BAYONNE, N. J.

Abstract

The effects of nickel with respect to melting point, fluidity, shrinkage properties and grain refinement are described for several common foundry mixtures. Although nickel brings a rise in melting point it frequently increases the fluidity, usually diminishes the grain size by about 50 per cent, and widens the useful range of pouring temperatures. Neither piping tendency nor linear shrinkage are appreciably affected by small nickel contents but in some mixtures at least capillary porosity is diminished. These useful effects are accomplished by nickel contents in general less than 3 per cent.

1. There are perhaps two reasons why it is desirable to study and record the effects of small nickel contents in copper casting alloys. In the first place, nickel changes in definite ways the strength and toughness as well as other properties of these alloys. While profound changes, such as those resulting from dispersion hardening, may be brought about by nickel in sufficient amount, particularly when in combination with tin or silicon, present interest lies more particularly in its milder effects in modifying, but not revolutionizing, the distinctive properties of these casting bronzes. The nature of these and the extent to which they can be usefully developed are of obvious interest to the foundryman and to the engineer.

2. In addition to this voluntary acceptance of nickel-modified bronzes, the increasing use of high-nickel-content casting alloys has an almost unavoidable consequence in the accumulation of fractional percentages of this element in the scrap circulation within the brass foundry, somewhat similar to the situation existing with scrap steel. Both of these aspects have induced the International Nickel Co. to devote attention in its experimental foundry toward establishing the effects of this useful but persistent element in the common foundry mixtures.

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NOTE: This paper was presented and discussed before one of the non-ferrous sessions at the 1932 convention of the American Foundrymen's Association.

3. About a year ago a paper¹ before this Association discussed the effects of nickel on the tensile and compressive properties of six types of bronze foundry mixture. The present paper continues this discussion to another group of properties, somewhat loosely lumped in the term "casting properties," and including a variety of characteristics more or less importantly related to the facility with which alloys may be handled in the foundry.

4. Some of these qualities are complex and, while evident enough in one way or another, are difficult to isolate for demonstration. Discussion of casting properties, therefore, is apt to lack the direct approach possible with other properties, but this vagueness should not be confused with unreality.

TYPES OF MIXTURE STUDIED

5. The plan which, in general, has been followed confines attention to a group of about a half dozen of the common brass foundry mixtures and to the response which they give to nickel contents generally not exceeding 3 per cent and made in substitution of a corresponding percentage of copper.

6. The melts all were prepared from new metals of high quality. These were ingot copper, tin and lead, "Horsehead" zinc, electrolytic nickel (usually in the form of previously prepared 50 per cent cupronickel), and 15 per cent phosphor-copper. The melts were made either as 150-lb. crucible charges or as 10-lb. melts in an Ajax high-frequency furnace.

7. In the case of the former, the copper and nickel were melted down in plumbago crucibles under a charcoal cover in an oil-fired pit furnace using a slightly oxidizing flame. Tin and zinc were added after fusion, and lead if added was delayed until the pot was ready for withdrawal. Phosphor-copper deoxidation (0.05 per cent maximum) was accomplished just prior to the casting operation. In the case of smaller induction furnace melts, similar materials were used and melting was done in an unlined Acheson graphite crucible.

8. Further details of production are noted when necessary in describing individual tests. In no case were scrap reverts melted, a point possibly of some consequence in considering the test data.

¹N. B. Pilling and T. E. Kihlgren, *Some Effects of Nickel on Bronze Foundry Mixtures*; TRANSACTIONS AND BULLETIN A. F. A., vol. 2, no. 7, pp. 93-110, July, 1931.

MELTING POINTS

9. As nickel raises the melting point of copper, and impairment of fusibility at times may be of considerable moment, it has seemed desirable to indicate with some definiteness the melting temperatures not only of simple nickel bronzes but of typical foundry bronzes containing nickel contents sufficient in amount to yield the properties elsewhere discussed.

Liquidus Temperatures of Nickel-Tin Bronzes.

10. The temperatures at which the completely molten alloy begins to freeze were measured for a considerable group of simple copper-nickel-tin alloys falling within the composition range 2 to 16 per cent tin, 0 to 10 per cent nickel. This group comprised some 46 alloys, well distributed throughout the range.

11. Ten-pound induction furnace melts were allowed to freeze in the furnace crucible while cooling curves were taken with a sheathed, noble-metal couple of light weight. The melt was kept in the reduced condition by a thick layer of crushed charcoal, which also served to prevent chilling of the surface. No soluble deoxidizer (likely to depress the melting point) was used.

12. The initial thermal arrests were clearly marked and were

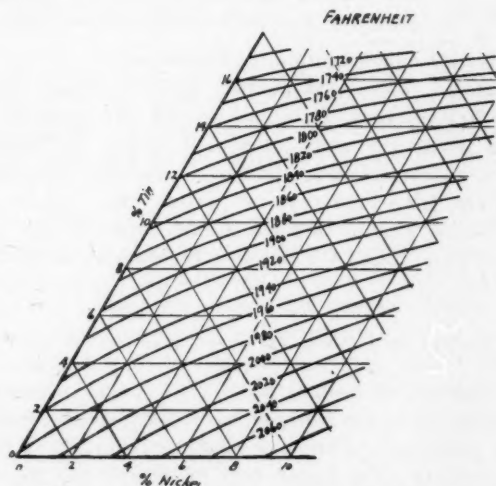


FIG. 1—LIQUIDUS TEMPERATURES OF NICKEL-TIN BRONZES.

Table 1

INCREASE IN MELTING POINT OF FOUNDRY MIXTURES
BY ADDITION OF 3 PER CENT NICKEL

No.	Composition				Rise in Melting Point, degs. Fahr.
	Cu	Sn	Zn	Pb	
5	89	11	..	..	40
6	88	8	4	..	33
7	85	5	5	5	50
8	70	1	27	2	42

checked against the known freezing points of the copper-tin alloys. The results are consolidated in Fig. 1, representing the temperatures of complete fusion of this portion of the ternary series. It is believed that the uncertainty does not exceed 15 degs. Fahr., and that the data therefore are adequate for general foundry guidance.

13. It may be seen from the curvature of the contour lines in this diagram that the rise in melting point resulting from a replacement of copper by nickel is not strictly proportional to the content of nickel, and this is particularly evident in the higher tin content alloys. As a general rule, the higher nickel contents result in less increase in melting point than would be suggested either by the corresponding nickel content in the copper-nickel series, or by the degree of rise indicated by lower nickel contents.

14. With bronzes containing approximately 5 to 10 per cent tin, the rate of increase in melting point by small additions of nickel (up to 3 per cent) in replacement of like amounts of copper, is 12 degs. Fahr. for each 1 per cent nickel. If nickel is substituted for an equal amount of tin, the melting point rises about 32 degs. Fahr. for each 1 per cent nickel. Should it be desired to introduce nickel with no increase in melting point, the tin content would need to be raised 0.7 per cent for each 1 per cent of nickel addition.

Change in Melting Point of Foundry Mixtures

15. The rise in melting point from nickel in several of the more complex foundry bronzes has been directly measured by preparing small melts of the base mixture, taking its freezing point and then adding to it 3 per cent of nickel, and repeating the operation. This method, it may be noted, introduces nickel by

dilution of the melt rather than by replacement of copper. (See Table 1.)

Effect of Nickel on Freezing Range.

16. A specific test of the often-discussed question, if nickel diminishes the freezing range of bronzes, was made with a simple 8 per cent tin bronze. For this purpose the temperature of first liquefaction on heating was determined by heating curves taken with a bare thermocouple riveted into the solid alloy. The result, shown in Table 2, indicates that nickel raises the solidus at just about the same rate that it raises the liquidus, with no net effect on the freezing range.

Table 2

EFFECT OF NICKEL IN FREEZING RANGE OF 8 PER CENT TIN BRONZE

No.	Analysis			Liquidus, degs. Fahr.	Solidus, degs. Fahr.	Freezing, Range, degs. Fahr.
	Cu	Sn	Ni			
1	91.92	8.00	0.02	1872	1614	258
2	90.93	7.87	1.00	1881	1630	251
3	90.16	7.75	2.11	1891	1639	252
4	88.73	8.24	3.02	1902	1645	257

FLUIDITY

17. One of the curious effects which nickel has on bronzes, and one which it is certainly difficult to explain, is the power of imparting fluidity or running power to the metal. Although the addition of nickel raises the melting point and on this account might be expected to diminish the ease with which the molten alloy reaches all parts of the mold, the reverse is found to be the case.

18. A considerable study of this effect has shown that in none of seven types of foundry mixture examined was the fluidity perceptibly impaired by as much as 1 or 2 per cent of nickel; several showed increases in length of run amounting to 40 per cent, induced by as little as 0.5 per cent nickel. This also has been found in practical foundry operations, and St. John,² for example, has described briefly the reduction in pouring temperature made possible by the presence of about 0.5 per cent nickel in two foundry bronzes.

² *Effects of Nickel on Bronze Foundry Mixtures*, TRANSACTIONS AND BULLETIN A. F. A., vol. 2, no. 7, July, 1931. Discussion by H. M. St. John, p. 11.

19. A study of this property was made by comparing the lengths of spiral ribbon cast in green-sand molds under careful control. While a fluidity test of this nature is simple in principle, its execution in practice is beset with many difficulties, among the most distressing of which are adequate temperature control and elimination of the momentum with which the mass of fluid metal enters the mold.

20. It may be desirable to describe in some detail the arrangement of the present fluidity test. Under ideal conditions the molten metal, at rest and at the desired temperature, would be put in communication with the spiral cavity and allowed to have its run under a constant static pressure. This is a difficult matter to arrange for temperatures approaching 2300 degs. Fahr. without an elaborate control mechanism.

21. In simplified tests, in which the metal is poured from a crucible into a test mold, these elements necessarily can only be brought under partial control owing to the competing demands of temperature and motion. The transfer of molten metal over the cool lip of the crucible into the cold sprue or reservoir feeding the spiral cavity must be accomplished quickly to avoid uncertain chilling, but bringing the moving stream to rest before it starts on its run requires time.

22. Trials with a variety of patterns led to the design shown

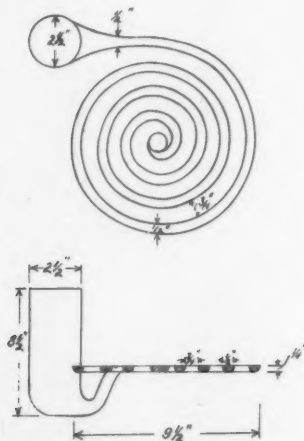


FIG. 2—FLUIDITY TEST SPECIMEN.

in Fig. 2, ordinarily molded in green sand. The test channel is semi-circular in section, terminating in a central vent. It is gated from below to the pouring head, the latter being large in section compared both with the channel and the emergent stream from the crucible. The molten metal enters the head with considerable velocity and energy; the level rises in the head but no metal enters the channel until the altitude of the spiral plane is reached, and since the rate of flow of melt from the crucible must be much greater than the rate of egress through the gate, the initial velocity head is probably largely dissipated in the pouring basin.

23. During the stage at which the spiral is run, which is brief, the large size of the pouring head limits any considerable increase in pressure head even though the rate of pouring from

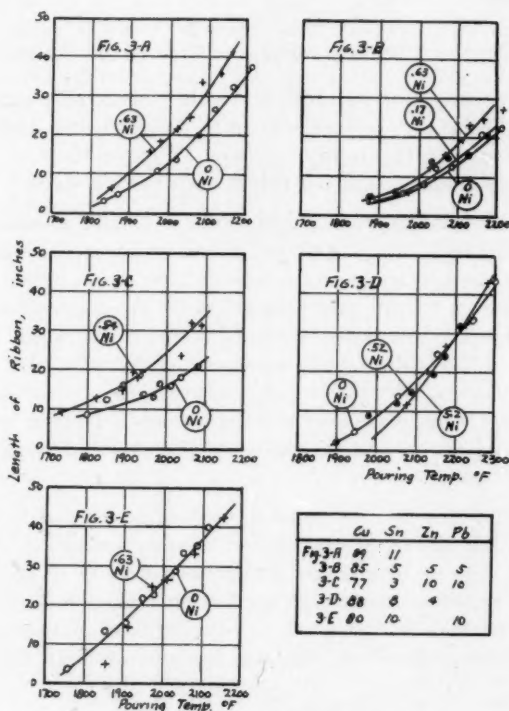


FIG. 3—FLUIDITY OF NICKEL BRONZES.

Table 3

MIXTURES IN FLUIDITY TESTS

Type	Analysis					
	Cu	Ni	Sn	Zn	Pb	P
Gear Bronze.....	88.58	nil	11.26	.....	.....	0.040
	88.60	0.63	10.67	.....	.....	0.037
Modified G-Bronze..	87.52	0.02	8.27	4.03	.....	0.021
	87.13	0.52	8.17	4.03	.....	0.020
	82.63	5.15	8.12	4.04	.....	0.032
Red Brass.....	84.11	0.02	5.12	4.96	5.73	0.051
	84.13	0.17	5.05	4.80	5.77	0.039
	83.60	0.63	4.93	4.94	5.80	0.050
Bearing Bronze.....	79.05	nil	9.85	.....	10.89	0.076
	78.10	0.63	9.89	.....	11.15	0.083
Locomotive Brass...	69.16	0.10	5.68	1.23	23.62	0.027
	70.12	0.61	6.42	1.25	21.47	0.026
Yellow Brass.....	72.46	0.04	1.19	24.57	1.61	0.038
	72.90	0.52	1.13	23.73	1.65	0.038
Valve Bronze.....	82.06	tr	2.48	9.85	5.49	0.068
	79.74	0.54	2.52	10.22	6.86	0.062

the crucible may not be uniform. Other types of pouring head in which a constant pressure is sought by overflow have not proven very successful with bronzes, perhaps owing to the fact that the run may be almost completed before the overflow stage is reached.

24. In operating the fluidity test, a 150-lb. crucible charge is melted down in an oil-fired pit furnace and superheated to the maximum desired temperature, about 2300 degs. Fahr. This is controlled by a robust, bare, immersion couple designed to operate directly upon the crucible contents before withdrawal from the furnace. After withdrawal, successive portions of the melt are cast at progressively lower temperatures as it cools down, the temperature being taken with a lightweight, Thwing immersion couple just prior to pouring each cast, the junction being renewed for each reading.

25. The results of a number of fluidity tests of bronzes are shown in Fig. 3. Of seven types of mixture examined, (Table 3) four gave definite indications of increased fluidity in the presence of slight nickel contents. This effect is typically shown, in the examples of Figs. 3-A and 3-C, to consist in an increased response to superheating above the liquidus temperature into the pouring range.

26. The effect, therefore, increases in magnitude as the pour-

ing temperature is raised. To take two of the more pronounced examples, Table 4 shows the increased lengths of spiral obtained with approximately 0.5 per cent nickel content, taking as reference points the pouring temperature for zero run. At about 2050 degs. Fahr. the increased latitude in pouring temperature thus afforded amounts to 70-100 degs. Fahr.

27. It appears from these tests that the magnitude of the fluidizing effect rises with increase in (moderate) nickel content and that the several base mixtures differ in the readiness with which they show response. The reaction of red brass has been checked by several trials and the curves of Fig. 3-B selected to illustrate the progressive nature of the change.

28. The 88-8-4 alloy showed no perceptible response with 0.5 per cent nickel content, yet a positive effect is discernible (Fig. 3-D) with 5 per cent nickel, although this is partially masked by the 60 degs. Fahr. rise in melting point. As a practical matter, 5 per cent nickel may be added to this alloy without loss of fluidity in the ordinary range of pouring temperature.

29. Fig. 3-E is an example of a mixture in which the fluidiz-

Table 4

Margin of Pouring Temp., degs. Fahr.	Percentage Increase in Length of Run	
	(Cu 89, Sn 11)	(Cu 78, Sn 3, Pb 10, Zn 10)
100	25	15
200	35	30
300	40	35
400	40	40

Table 5

FLUIDIZING POWER OF NICKEL

Composition				Per Cent Nickel.	Fluidizing Action.
Cu	Sn	Pb	Zn		
89	11	..	..	0.6	Marked
88	8	..	4	0.5	None
				5.2	Moderate
70	1	2	27	0.5	None
85	5	5	5	0.2	Slight
				0.6	Moderate
80	10	10	..	0.6	None
77	3	10	10	0.5	Marked
72	7	20	1	0.6	None

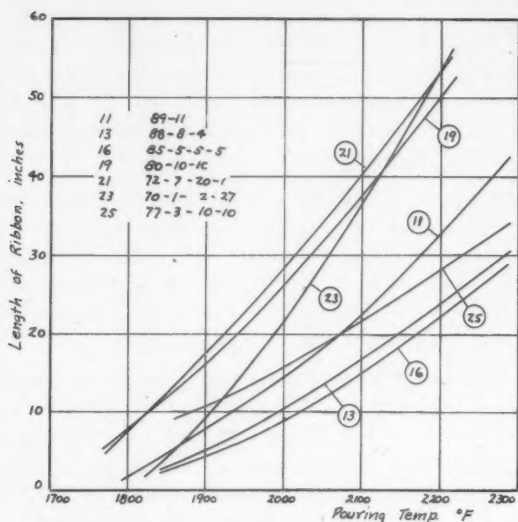


FIG. 4—FLUIDITY OF FOUNDRY MIXTURES.

ing action is not found by this test, and Table 5 summarizes the data now available.

30. This series of tests permits some interesting comparisons to be made between the running power of several types of foundry mixture (Fig. 4). Taking the simple tin-bronze as a basis of comparison, the addition of 10 per cent lead results in a remarkable rise in fluidity, while zinc appears to diminish this quality.

GRAIN SIZE

31. True grain size is probably only one of several factors affecting the texture of a fracture. Refinement of grain thus may have its origin in the elimination of internal oxidation or the dispersal of incipient shrinkages, as well as in changes in size or in shape of the grains composing the casting. Nickel contributes to both of these latter two factors in bronzes. The appraisal of fractured surfaces is highly qualitative, and even photography has its limitations in recording differences which may be obvious to a practiced eye.

32. In a number of cases which have been examined, nickel appears to have a real effect in reducing the true grain size, ex-

pressed as the average grain diameter. In the usual range of pouring temperatures the refinement averages about 50 per cent reduction in grain diameter for 1.5 per cent nickel or less.

33. Six mixtures with nickel contents up to 3 per cent have received study, and details of their composition are given in Table 6. These were produced from 150-lb. crucible charges cast at a succession of diminishing temperatures over a range of about 450 degs. Fahr. into cylinders of $1\frac{3}{4}$ in. diameter and 9 in. high, molded in green sand and weighing about 6 lbs. each. The sections examined were transverse slices cut about $2\frac{1}{2}$ in. from the bottom end of the cylinder.

34. The measurement of the diameter of the coarsest grains was made by drawing a circle on the flat, etched surface and counting the number of grains wholly and partially included, fol-

Table 6
COMPOSITION OF NICKEL BRONZE MIXTURES

Type	Analysis					
	Cu	Ni	Sn	Zn	Pb	P
Gear Bronze.....	88.70	0.03	11.12	.....	.....	0.026
	88.26	0.47	11.03	.....	.....	0.030
	87.14	1.47	11.34	.....	.....	0.021
	85.82	2.94	11.13	.....	.....	0.013
Modified G-Bronze.....	87.95	0.02	8.39	3.57	.....	0.027
	87.67	0.58	7.91	3.66	.....	0.028
	86.13	1.70	8.43	3.65	.....	0.047
	85.11	3.21	7.90	3.60	.....	0.036
	82.64	5.32	7.96	4.02	.....	0.015
Red Brass.....	83.85	0.03	4.83	5.22	6.01	0.036
	83.60	0.48	4.93	5.07	5.83	0.036
	81.93	1.60	5.12	5.14	6.13	0.036
	81.30	3.03	5.00	4.65	5.94	0.040
Yellow Brass.....	70.90	0.03	1.08	25.22	2.60	0.037
	69.03	0.62	1.18	26.62	2.49	0.030
	71.08	1.63	1.32	23.56	2.33	0.033
	68.23	3.07	1.28	25.05	2.30	0.028
Bearing Bronze.....	78.45	0.03	10.02	.....	11.44	0.041
	77.64	0.67	10.06	.....	11.56	0.037
	77.28	1.57	9.84	.....	11.24	0.027
	75.14	2.92	10.34	.....	11.55	0.021
High-Lead Bearing Bronze.....	67.50	nil	6.21	1.49	24.90	0.024
	68.99	0.23	7.02	1.13	22.55	0.021
	70.08	0.47	7.10	1.30	21.08	0.030
	69.90	1.46	7.36	1.18	19.93	0.035
	67.86	2.88	6.10	1.02	22.25	0.012

lowing the Jeffries method. A similar procedure was used for the finer grained materials with the microscope.

35. The highly leaded alloys were more difficult, owing to the complexity of the structure and the lack of grain contrast developed in etching. These were handled by a method of visual comparison of the texture of the etched surfaces with similarly prepared surfaces having known average grain diameters.

36. A typical series, showing the rate of coarsening of grain with rise in casting temperature and refinement of grain with rise in nickel content, is given in Fig. 5. Mixtures containing high zinc or lead contents ceased to coarsen when superheated sufficiently, a trait which the nickel content did not appreciably modify. These mixtures, and the pouring temperatures at which maximum coarseness of grain developed, are given in Table 7.

37. A condensed resume of the grain-refining action of nickel on each mixture is given in Fig. 6. With the exception of 88-8-4, each may be considered to respond favorably, the most effective nickel content varying from 0.5 to 2 per cent. In all these cases,

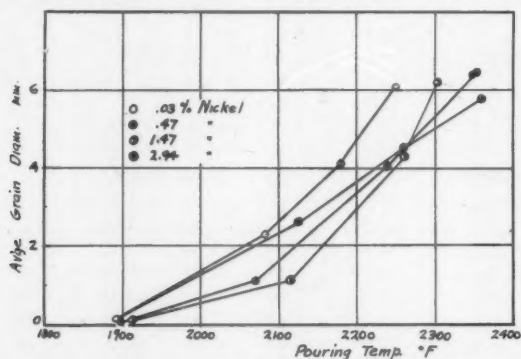


FIG. 5.—GRAIN REFINEMENT OF 89 PER CENT COPPER, 11 PER CENT TIN BRONZES WITH VARYING NICKEL PERCENTAGES.

Table 7

CRITICAL POURING TEMPERATURES

Mixture	Temperature, degs. Fahr.
Yellow Brass.....	1980
Red Brass.....	2100
Bearing Bronze.....	2130
High-Lead Bearing Bronze.....	2020

the action is substantially complete below 3 per cent nickel content. The extent of the grain refinement is appreciably affected by the temperature of casting.

38. Fig. 7, developed for the best nickel content for each mixture, brings out the point that refinement is greatest at low pouring temperatures and frequently amounts to as much as 60 per cent. With rising temperature the refining effect diminishes

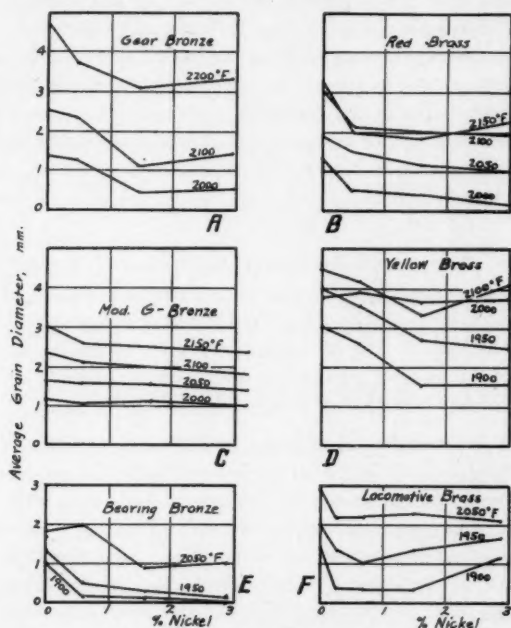


FIG. 6—GRAIN SIZES OF NICKEL BRONZES.

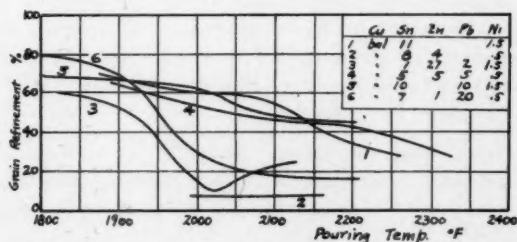


FIG. 7—EFFECT OF POURING TEMPERATURE ON GRAIN REFINEMENT.

in magnitude, gradually or suddenly, and may persist to quite high degrees of superheat. Poured very cold, *i. e.*, at or below the liquidus, the grain size always is very fine with no effect traceable to the nickel content.

FREEZING SHRINKAGE

39. In common experience there are two opposing effects of nickel which lend some uncertainty to its ultimate action on the shrinkage of copper alloys. The persistently observed, yet difficultly demonstrated, consolidating action of small nickel contents—which is variously expressed as tightening the grain, solidifying, densifying or reducing the leakiness of foundry bronzes—probably is the combined result of several factors and presumably the shrinkage characteristics are favorably modified to assist in this. On the other hand, high-nickel-content alloys are notoriously “high shrinkage” and difficult to handle.

40. A study of the shrinkage properties of several foundry mixtures, both free of nickel and containing a substantial content, suggests that neither the true freezing shrinkage nor the habit of concentrating or dispersing the “pipe” is easily modified to any important degree except by substantial contents of the elements ordinarily present in bronzes, including nickel.

41. For example, aluminum bronze retains its pronounced pipe unchanged by 3 per cent nickel content; the moderate tendency for piping of red brass is similarly unaffected; and an alloy such as 11 per cent tin bronze, which ordinarily does not pipe, shows no sign of developing one when 3 per cent nickel is present. This points by inference to a modification in the character of highly dispersed or incipient shrinkages, and some evidence in support of this has been developed.

42. A number of mixtures have been examined by the method recently described³ for the measurement of freezing shrinkage, and a summary is given in Table 8. In essence, this method determines total shrinkage and linear shrinkage, deriving the freezing shrinkage by difference.

43. Since linear shrinkage begins to accumulate at a temperature probably somewhat below the solidus temperature, particularly with leaded bronzes, changes in apparent freezing shrink-

³ N. B. Pilling and T. E. Kihlgren, “A Method for the Study of Shrinkage and Its Distribution in Castings”; presented before 1932 A. F. A. Convention, Detroit.

age need to be considered in relation to total shrinkage. While the tabulation indicates, in general, a slight reduction in freezing shrinkage of the nickel-bearing mixtures, it is not believed that this is wholly beyond experimental uncertainty.

SHRINKAGE DISTRIBUTION IN NICKEL RED BRASS

44. Taking densifying action to be in part synonymous with reduction in dispersed or "incipient" shrinkage, it is of particular interest to follow this in one of the commonest mixtures used for pressure castings—red brass. So great is the uncertainty of direct demonstration making use of pressure tests on hollow castings, that this requires in common experience the accumulation of statistical averages to give guiding trends.

45. The reason for this, of course, is evident. The hydraulic test reveals porosity only when a completed channel exists from inside to outside, and is unable to distinguish between a wholly sound section and one in which porosity is sealed in by a sound veneer. It is of considerable advantage, therefore, to make use of the contact print method of examining a section referred to in paragraph 42.

46. Crucible melts of the 85-5-5-5 mixture, of 150-lb. weight,

Table 8
EFFECT OF NICKEL ON FREEZING
SHRINKAGE OF BRONZES (NICKEL REPLACES COPPER)

Composition				Nickel Content, Percent	Total Volumetric Shrinkage, Melting	
Cu	Sn	Zn	Pb		Point to Room Temp., Percent	Freezing Shrinkage, Percent
89	11			0	11.0	6.1
				3	10.2	5.2
88	8	4		0	12.0	6.7
				3	11.8	6.5
85	5	5	5	0	10.8	6.5
				3	11.3	7.0
80	10		10	0	11.2	7.3
				3	10.7	7.2
72	7	1	20	0	9.7	5.5
				3	9.3	4.8
70	1	27	2	0	12.3	6.4
				3	12.1	6.2

were prepared and cast into T-shaped test specimens over a range of temperatures of 1850-2300 degs. Fahr. Similar casts were made from the alloy in which nickel contents up to 2 per cent were provided. The test specimen was a $3/4 \times 3 \times 3$ in. plate with a $1/4 \times 3 \times 1-1/2$ in. rib extending across its face. These were molded in pairs in green sand, rib down, using a horn gate and heavy risers. The series of specimens was cut into transverse slices, which then were subjected to examination.

47. Fig. 8 presents a selection from this study which brings out some interesting points. The unsoundness resulting from excessively high pouring temperatures is strikingly evident, but the progressive action of nickel in reducing the capillary voids, first in the chilled rib and then by increasing the depth of the sound chill in the heavier section, is brought out quite clearly. At lower pouring temperatures the general soundness is greatly improved, but the trend of nickel in driving in the area of porosity still may be traced.

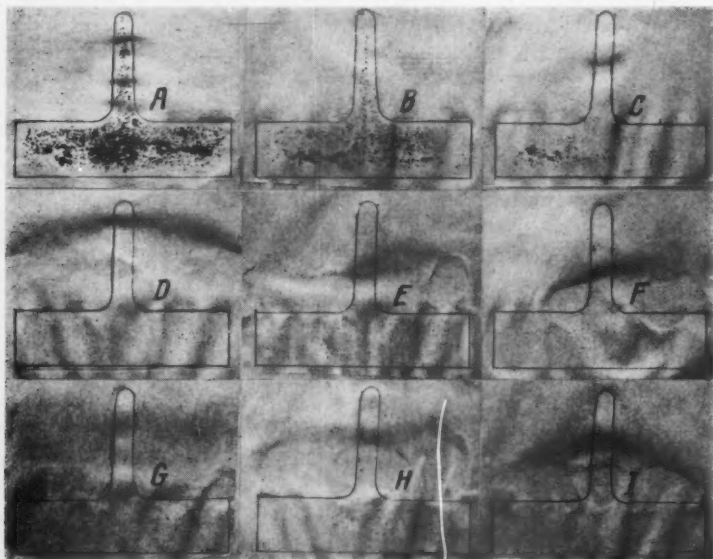


FIG. 8—EFFECT OF NICKEL ON DISTRIBUTION OF SHRINKAGE IN RED-BRASS SAND CASTINGS. POURING RANGES IN DEGS. FAHR.: A, B, C, 2250-2300; D, E, F, 2070-2125; G, H, I, 2000-2025. NICKEL CONTENTS, PER CENT: A, D, G, ZERO; B, E, H, 0.5; C, F, I, 2.0.

Table 9
EFFECT OF NICKEL ON
LINEAR SHRINKAGE OF BRONZE MIXTURES

Composition				Linear Shrinkage, Percent	
Cu	Sn	Zn	Pb	Nickel, = 0 Percent	Nickel, = 3 Percent
89	11			1.64	1.65
88	8	4		1.76	1.75
85	5	5	5	1.44	1.42
80	10		10	1.29	1.17
72	7	1	20	1.41	1.49
70	1	27	2	1.98	1.95

48. For this mixture at least, nickel may be said to increase the depth of the pore-less chill and to extend upwards the range of useful pouring temperatures in which soundness is possible. These effects, noticeable at 0.5 per cent, are further increased at 1 per cent and 2 per cent nickel.

LINEAR SHRINKAGE

49. As might be expected, small nickel contents have a scarcely perceptible effect on the linear shrinkage of bronze mixtures substantially free from constituents which remain fluid below the nominal solidus temperature. Highly leaded bronzes remain plastic to considerably lower temperatures and hence, have unusually low and irregular linear shrinkages. The effect of nickel on these is uncertain. (See Table 9.)

DISCUSSION

ORAL DISCUSSION

C. H. MORKEN:¹ Is anything known about the effect of nickel, particularly in high-lead alloys, on the lead sweat or combination of lead and tin sweat? I have in mind a peculiar alloy now being made, containing 60 per cent lead, 38 per cent copper and 2 per cent nickel. My understanding is that 2 per cent nickel is introduced to act with some of the orthodox sulphur and prevent a lead sweat. Is anything known about

¹ Detroit Electric Furnace Co., Detroit.

this problem in connection with such an alloy, or an alloy of lesser lead content—for example, one of 15 per cent lead?

T. E. KIHLGREN: It is generally believed that nickel materially aids in the distribution of lead in the leaded bronzes, but I can give no information on an alloy of the properties mentioned.

G. H. CLAMER:² Nickel has been used for thirty-three years for the purpose of getting better distribution of lead in the high-lead bearing bronzes. The Pennsylvania Railroad for a number of years made a packing metal somewhat similar to the alloy mentioned, my recollection being that it contained 6 per cent nickel, 20 copper, and 74 lead.

That alloy was successfully used for some ten years on the Pennsylvania, on all their locomotives for piston packings. More recently, however, it has been superseded by the straight 50 copper, 50 lead alloy, or perhaps 55 copper and 45 lead (I am not sure which). The reason for this change is primarily that such rings have been found to give better service in longer life.

I believe there is no question about the effect of nickel in helping to hold the lead in suspension. We always have attributed it to the fact that nickel raises the solidifying point of copper in a copper-lead-nickel alloy, and also the copper-tin constituent in a copper-tin-lead-nickel alloy; consequently, it mechanically holds the lead in suspension—that is, the matrix freezes at a higher temperature.

I am particularly interested in this paper because it brings out much information of great value to the ingot industry. We who have been engaged in specification work for the last few years have had the question of nickel content come up for discussion many times.

As has been pointed out, nickel generally has been looked upon as an impurity. Almost all scrap brass today contains some nickel, and it is practically impossible to get away from nickel in making ingot metal. Nickel is an element that cannot be eliminated by the ordinary methods of making ingot, and it therefore is necessary to accept whatever nickel content the ingot metal happens to have.

In ordinary red brass we find nickel contents ranging from 0.2 to perhaps 0.6 per cent, and occasionally a little higher. The nickel content is accounted for mainly because of nickel-plated scrap used in the furnace charge.

The information presented by the authors very thoroughly indicates that nickel surely is not detrimental; in some respects it is beneficial, to practically all the alloys.

The A. S. T. M. specifications restrict nickel content to 0.50 per cent. The data submitted in this paper give assurance that the limitation on maximum content in the specifications is quite practical. It might be necessary in the future to raise the limit a little higher as more and more nickel gets into our scrap metal.

Nickel finds its way into ingot metal by a cumulative process. Nickel cannot be refined out of the metal, and every time it is melted we probably add a little more.

² President. Ajax Metal Co., Philadelphia.

We have been confronted by a similar condition with antimony. Some years ago there was little antimony in scrap, but today it is entering the scrap in increasing amounts. In the case of antimony, however, we have a decidedly detrimental element and it is necessary to restrict rigidly the upper limits.

The curves shown in the paper exhibiting the fluidity of the different alloys were very enlightening. I was impressed particularly with the lack of fluidity of copper-base alloys of high zinc content as compared with the same class of alloys with tin, lead and tin, and also lead and zinc. The high-zinc alloys, I presume, contained no phosphorus. It is surprising to note what just a small amount of phosphorus will do in increasing the fluidity.

This paper is decidedly valuable since it gives us definite information on nickel such as we have been wanting for a number of years. I wish to express my appreciation to the authors and to the International Nickel Co. for having conducted the experiments.

FRED L. WOLF:² Have the authors made a study as to the influence of nickel on the corrosion-resisting properties of some alloys? I am particularly interested in atmospheric corrosion. For instance, I know that in steam electrification work some of the very high nickel alloys—Monel metal, for example—do not last very long. On the other hand, we have seen some samples of red brass (about 5 per cent nickel) which have shown exceptional properties for resisting corrosion.

T. E. KIHLEBEN: No such study of this kind has been made as yet. We might assume, however, that the addition of nickel would improve the corrosion resistance of red brass.

N. B. PILLING: Nickel improves corrosion resistance under certain conditions; but in strongly sulphurous, damp atmospheres such as in railroad tunnels, a high nickel content is not necessarily an advantage.

FRED L. WOLF: I have seen red brass, about 79 per cent copper and 5 per cent nickel, which showed quite a resistance. There must be some point at which nickel improves this property, but beyond which it does nothing to improve resistance.

N. B. PILLING: Vernon has been carrying on studies of atmospheric corrosion in England, in industrial atmospheres. One of his tests included copper with small amounts of arsenic and nickel. He found in both cases that the rate at which the first filming-over occurred was hastened by each of these elements, but that in the long run the total weight loss, continuing over a number of years, was just the opposite. Nickel to the extent of 2 or 3 per cent gave the quickest tarnishing but the lowest ultimate corrosion.

E. R. DARBY:⁴ There is an alloy used quite widely by the automotive industry, as a synchronizing ring in the transmission, containing from 1 to 3 per cent nickel according to various specifications. Tin ranges

² Chief Engineer and Technical Superintendent, Ohio Brass Co., Mansfield, Ohio.

⁴ Chief Metallurgist, Federal Mogul Corp., Detroit.

from 10 to 12 per cent. A number of these specifications call for heat treatment in a *Homo* furnace at 800 degs. Fahr.

Could the authors tell me what is the effect of such treatment, and why such heat treatment is specified? I have asked this question of a number of users and have received varying answers, which did not state clearly just why it was used. Some claimed there was a distinct hardening effect in the low-temperature anneal; others claimed it was simply to relieve stress or strain in the material; still others claimed the treatment was for softening. It would be a great help to learn something about the effect of heat treatment on the composition mentioned.

T. E. KIHLGREN: The addition of such a small amount of nickel could not be expected to bring about any of the hardening effects noticeable with higher amounts of nickel on that amount of tin. The only thing I have noticed with very small nickel additions is that it affects internal structure of the eutectoid to some extent.

E. R. DARBY: What would be the probable effect of 2 per cent nickel on the liquidus-solidus of an alloy of that sort?

T. E. KIHLGREN: We have found on the straight tin bronzes that there is no change in the freezing range; that is, as nickel is added to the straight tin alloy, the liquidus and the solidus rise at about the same rate. The freezing range apparently is unaltered.

MEMBER: I was interested in Mr. Darby's question with regard to the pure bronze containing 2 per cent nickel, and the point he brings up about the heat treatment. Our experience has been that there is a difference in the hardness of castings from the same heat of metal due to the length of time they are left in the mold, in the sand, and so on. After heat treating 200,000 or more of these castings, we have found that heating at 800 degs. Fahr. for an hour and air cooling does not increase the hardness of the hard ones, but that it does level them out; it will bring the level of the soft ones up with the others.

In other words, the result of this heat treatment is to obtain more uniform elongation, more uniform machinability, and other more uniform physical properties in the metal than are obtained in castings simply coming from the mold.

MEMBER: At what stage of the melting operation was the nickel added in these experiments of the authors? Also, at what temperature was the metal melted? To me it seems that, when considering the higher melting point of nickel with that of the alloy, for example the 85-5-5-5, the alloy would have to be overheated to have the added nickel melt.

T. E. KIHLGREN: The nickel was added as 50-50 copper-nickel at the same time the copper was put into the crucible. It is not necessary to superheat for the purpose of causing nickel to alloy with bronze, as it will dissolve completely far below the melting point of nickel.

H. M. ST. JOHN:⁵ We have been very interested for several years in

⁵ Metallurgist, Detroit Lubricator Co., Detroit.

the use of nickel in foundry brasses and bronzes. Practically all our alloys at the present time contain from 0.5 to 2 per cent nickel, and the results have been very favorable.

This paper clarifies the situation by giving a definite form to certain facts which for some time many of us have believed to be true, but the exact character of which we did not know. I am particularly interested to note that, probably more by luck than by good sense, the percentages of nickel we use in our various alloys seem to hit the most favorable points brought out by the authors.

With reference to Mr. Darby's question, we do not make such rings as he has mentioned, but a good friend of ours brought some to use one day because we have a Homo furnace. He wanted us to find out just what would happen, and we ran several small test lots of the rings through the Homo furnace. As it happened, all the rings were fairly hard when received. The hardness was unaffected by the heat treatment.

Several times this paper refers to lubricator bronze, the composition listed bearing a rather close resemblance to one of the alloys used by the Detroit Lubricator Co. However, I would call attention to the fact that it is not used to make lubricators. Lubricator bronze must not contain more than 5 per cent lead.

Materials Handling in the Small Brass Foundry

By D. G. ANDERSON* and B. F. MCAULEY,† CHICAGO

Abstract

The engineers of the Hawthorne works of Western Electric Co. were given the task of reducing costs and securing better quality of castings in the brass foundry. Because of the foundry being of medium size, careful studies were made to determine improvements which would surely prove economical. Equipment for sand handling and mold handling of the continuous type was installed, and electric melting furnaces were secured. The paper describes in detail the sand-handling and sand-conditioning equipment, methods of pouring and handling molds, and cleaning arrangements. Results have been such as to justify the methods installed in this, a small brass foundry.

1. One of the recent trends in foundry practice, as in numerous other industries, has been the development of equipment to speed up production by improvements in materials handling methods. There are few foundries exactly alike, yet there are a great many foundries which are faced with the problem of installing improved equipment to reduce costs and meet present-day competition.

2. However, the foundryman planning to improve his plant may find it difficult to decide upon what sort of equipment and layout will serve him best. This is because the improved equipment must be correctly applied to the local conditions existing in each particular foundry.

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NOTE: This paper was presented and discussed before the Joint A. F. A.-A. S. M. E. session on materials handling at the 1932 convention of the American Foundrymen's Association.

3. The brass foundry at the Hawthorne Works of the Western Electric Co. is devoted to the production of nonferrous castings that are required in the manufacture of telephone equipment. It occupies an area of 75×125 feet in a wing of the main foundry, and its normal capacity has been doubled within recent years by the introduction of new equipment.

4. The majority of the individual castings made in it are small and of a wide variety of design. Accordingly, it can be considered in the small or jobbing foundry class.

5. While such a small foundry does not lend itself as readily

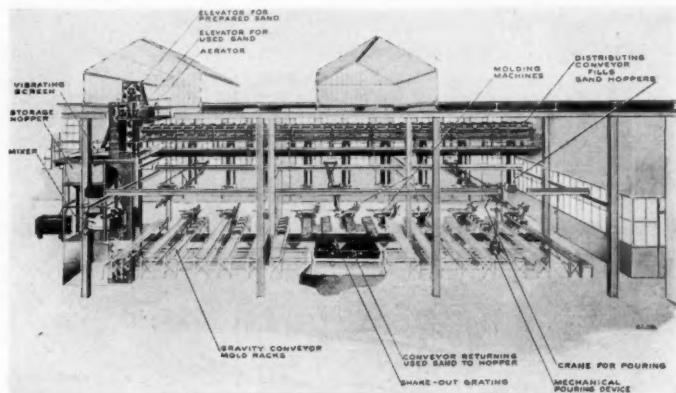


FIG. 1—DIAGRAM OF GENERAL ARRANGEMENT OF BRASS FOUNDRY.

to mechanical handling as do larger foundries which are laid out on a basis of heavy production schedules, it has been found that the introduction of more efficient equipment with the improved sequence of operations described below has been justifiable.

FOUNDRY EQUIPMENT AND PROCEDURE

6. Fig. 1 is a schematic view of the general arrangement of the foundry, and Fig. 2 shows a diagrammatic section of the sand-conditioning unit.

7. Shakeout sand is dumped through protected openings in the floor onto an 18-inch rubber-covered conveyor belt which carries the sand to the boot of an enclosed elevator. The returned

sand is carried upward by a standard bucket elevator with buckets mounted on a rubber-covered belt, and discharged onto a vibrating screen. The screen cloth has a diagonal mesh of $1/4 \times 1$ inch which permits the sand to flow through it into a storage hopper. Any cores and bits of metal are discharged over the screen into a container on the floor.

Control of Sand Condition

8. From a measuring hopper of 10 cu. ft. capacity, located at the bottom of the storage hopper, the used sand is discharged into a mulling type of sand mixer. Here both water and new sand are added in order to bring the sand up to its proper consistency for molding.

9. Water is added by means of a gravity flow from a small measuring tank. It enters the mixer from six nozzle openings located around the edge of the machine. The relative moisture is determined by an electrical resistance moisture-meter installed on the mixer. This instrument has proved to be very valuable in maintaining a uniform moisture in the sand.

10. After a mixing of approximately three minutes, the

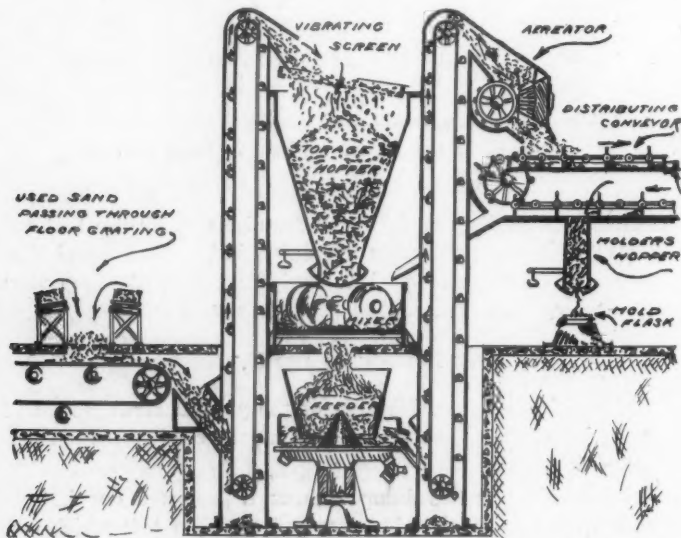


FIG. 2—THE NEW METHOD OF HANDLING MOLDING SAND.

prepared sand is discharged on a table-feeder located in a pit under the mixer. The table-feeder has a raised conical section at the center. This tends to throw the sand against a fixed retaining plate around the circumference of the table as the latter rotates.

11. There is an opening between the table feeder and the housing through which a plow is inserted to scrape sand off the rotating table. The rate at which sand is discharged from the table-feeder is regulated by the setting of the plow.

12. This feature permits continuous feed from the table as the plow deflects the sand to a bucket elevator from which it is discharged into an aerator. In passing through the aerator, the

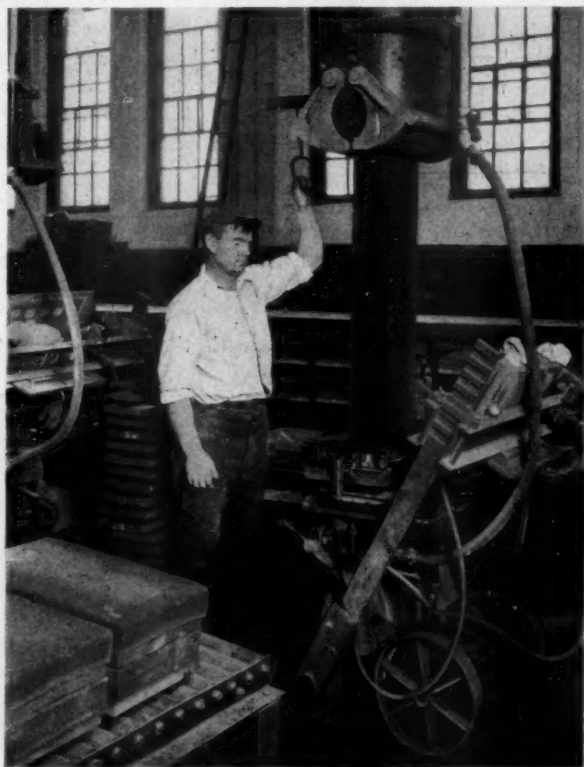


FIG. 3.—FILLING MOLD FLASK FROM OVERHEAD HOPPER.

sand is thrown at high velocity through a series of wire brushes that break up any small lumps which may be present. The sand is light and fluffy when discharged from the aerator to the flight conveyor.

Conveying Conditioned Sand

13. The aerated and conditioned sand is conveyed to the molding positions by a double-deck drag conveyor 15 inches wide and 7 inches deep, with flights spaced on 18-in. centers. The flights are carried on a roller chain that runs on light rails. At the operating speed of 40 ft. per min., the capacity of the conveyor is 25 tons of prepared sand per hour. The flights travel in built-up rectangular troughs open at the top.

14. Sand from the aerator is carried in the upper trough to the far end of the conveyor, where it is dumped over the take-up end into the lower trough. The molders' hoppers are filled automatically as the flights in the lower trough pass over openings leading to them. Three of the flights are fitted with rubber tips in order to keep the conveyor free of any sand that may accumulate and dry out.

15. The molders' hoppers are circular, with a diameter of 14 inches at the top and 16 inches at the gate. This prevents the sand from sticking in the hoppers and insures a positive flow whenever the discharge gate is open, as shown in Fig. 3. A general view of molding positions is shown in Fig. 4.

16. Deflectors are mounted beneath the gate to direct the



FIG. 4—GENERAL VIEW OF MOLDING BAY, SHOWING ARRANGEMENT OF MOLD CONVEYORS AND MACHINES.

falling sand into the center of the flask on the molding machine below. The entire construction of the hopper eliminates waste time due to clogging sand and unnecessary spillage.

Mold Conveying Problems

17. The completed molds are placed on roller conveyors of the lateral-slope type. Unprotected molds made in snap flasks are used exclusively. Ordinarily, molds are contained in flasks when moved on a roller conveyor; but experiments proved that unprotected molds could be conveyed successfully by employing protecting contacts, that is, cleats on the bottom board which protect approximately one-half inch, making a separation of one inch between molds.

18. The flask sizes are selected to produce the maximum number of good castings per day. This usually is not the largest flask or the pattern design that produces the greatest number of castings in one mold. Large flasks cause fatigue, and small patterns grouped close together frequently cause the separating sand walls to fracture when the pattern is drawn.

19. We have found by experience that the largest mold which can be used economically is 10×18 in. with 4 in. cope and drag. Furthermore, the most satisfactory mold size, from the standpoint of convenience of handling, is 10×14 in., with up to 4 in. cope and drag.

Inspection and Maintenance

20. The complete sand-preparation and sand-handling unit is so constructed that it can be easily inspected and maintained. All the overhead equipment is readily accessible from a walk-way that extends the length of the conveyor. The underground equipment has lighted walk-ways along its entire length. This not only facilitates repairs, but enables the pits to be kept clean.

21. Moving units are equipped with individual drives and, except for a belt drive on the vibrating screen and a direct motor-drive on the aerator, herringbone-gear speed reducers are used. All moving parts are equipped with grease fittings, and the bearings are protected from sand and dust.

22. The sand-handling equipment is controlled from a push-button control panel with pilot lights for each unit. All units of

the prepared-sand and shakeout-sand systems are electrically interlocked so that no material may be conveyed until all units are in operation. This prevents sand from piling up at any point should one unit stop.

SAND CONTROL

23. Since the functioning of the above-described unit depends on the uniformity of molding sand, it was necessary to introduce a control on the consistency of the sand. Accordingly, sand-testing laboratory was set up having equipment conforming to standard or tentative methods of test of the American Foundrymen's Association. This is shown in Fig. 5.

24. Inasmuch as uniform mixing is necessary to produce uniform results, a limit was set on the mixing time. It was found that the desired results were obtained if water was added one-half minute after the sand had been charged into the mixer and if the sand was discharged two minutes after the mixer had been charged. At no time is the sand allowed to remain for a longer period than four minutes.

25. In order to replenish losses, new sand additions are made at intervals of not less than one-half hour. Each of these charges is introduced through the openings of the shakeout system, and consists of not more than 200 lbs. By using this procedure the new sand is distributed uniformly in the storage bin and, hence, throughout the system.



FIG. 5—TWO VIEWS OF SAND-CONTROL LABORATORY. *Left*: TESTING FOR CLAY CONTENT. *Right*: TESTING FOR STRENGTH.

Benefits Resulting from Sand Control

26. A control of the consistency of the sand has proved of great advantage in controlling the quality of product. The results of it have manifested themselves in a reduction of scrap due to holes, warped castings, "drops," "blows" and "washes." The uniform sand has enabled the molder to regulate his machine-molding practice and to use the same molding pressure day after day for a given job. The pourer also depends upon the moisture content being uniform in determining the temperature for the metal and the chill effect within the mold.

MELTING AND POURING EQUIPMENT AND PROCEDURE

27. Electric rocking arc furnaces having an output of 1400 lbs. per hour are used for melting the various brass alloys. With these furnaces it is possible to use considerable quantities of scrap punchings and baled copper wire in the charges. Since the atmosphere is kept free of oxygen by the burning carbons, no difficulty is experienced in regulating the mix or controlling the melt.

Great Attention Given Safety and Health

28. The complete melting equipment occupies an area of 720 sq. ft., all of which is located under a hood from which the hot gases and fumes are removed by an exhaust system. The quantity of air removed in this manner has a beneficial effect on the whole foundry, in that the positive circulation of air greatly reduces the quantity of dust particles in the atmosphere.

29. Cast-iron plates, covered with carborundum and flush with the concrete floor, are placed between the pedestals and in front of each furnace. These plates protect the floor from spilled metal and provide good footing for the operator. A small sheet-metal deflector that can be easily removed is mounted over the furnace opening to disburse glare as much as possible.

30. The crucibles of molten metal are conveyed from the furnace on a small dolly truck, which eliminates the hazard of spilled metal. The dolly fits between the furnace pedestals, as shown in Figure 6. A general view of the furnace installation is shown in Fig. 7.

31. When the crucible has been filled, the dolly is moved clear of the furnace. The crucible with the pouring device then



FIG. 6—ELECTRIC FURNACE MELTING UNIT. CRUCIBLE ON SMALL DOLLY TRUCK, WHICH ELIMINATES HAZARD OF SPILLED METAL. NOTE ARRANGEMENT FOR CONTROL OF SAFETY LADLE HOLDING DEVICE.

is picked up on a monorail system serving the mold storage floor, each bay of which is equipped with a traveling monorail that provides accessibility to each of the pouring racks in it.

32. The pouring of molds is handled by experienced men, while the molders remain at their machines. Alternate molds on the storage lines are poured (see Fig. 8), after which the mold weights are placed on the adjacent molds and the remainder poured. The transfer of the hot mold weights is made with tongs that fit into recesses in the top of the plates, as shown in Fig. 9.



FIG. 7—GENERAL ARRANGEMENT OF MELTING UNITS. ELECTRIC-FURNACE CONTROL BOARD IN BACKGROUND.

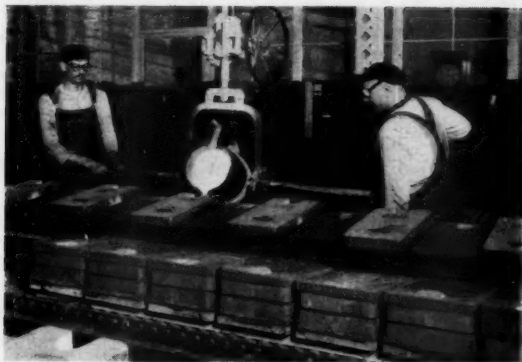


FIG. 8—POURING ARRANGEMENT. MOLDS ARE POURED BY SPECIAL POURING CREWS.

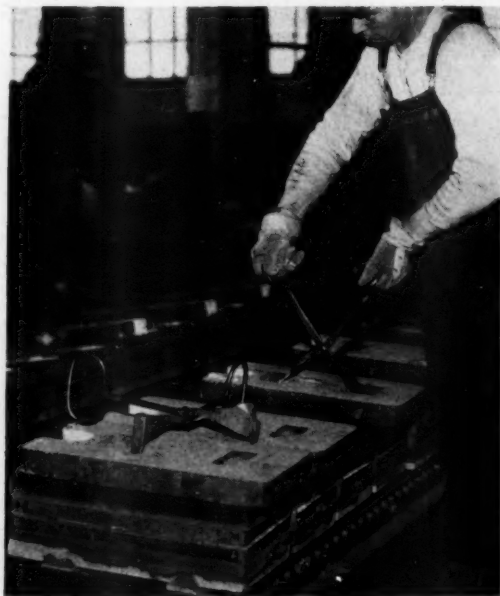


FIG. 9—TONG METHOD FOR HANDLING HOT WEIGHTS.

The use of such tongs greatly reduces the hazards of the manual handling operation.

CLEANING EQUIPMENT AND PROCEDURE

33. Sandblasting is used for cleaning the castings because the cutting action of the sand stream removes all scale from the surfaces exposed to the direct action of the blast. Small castings are cleaned in two sandblast barrels consisting of a rotating cylinder which contains the parts and tumbles them in the path of the sand stream.

34. A 200-lb. charge of medium-size castings is thoroughly cleaned in ten minutes, or in one-third the time required with water tumbling barrels. Large castings are cleaned rapidly and without dust in a sandblast cabinet. Fig. 10 shows this equipment.

CONCLUSIONS

35. The studies and changes effected have demonstrated that production methods can be applied economically in a jobbing foundry. The important developments brought out in the Western Electric Co. installation are as follows:

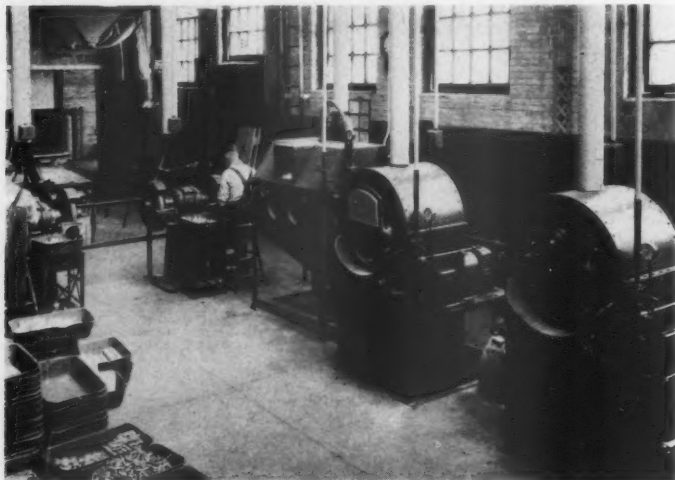


FIG. 10—VIEW OF CLEANING ROOM AND EQUIPMENT.

(1) That one grade of molding sand can be used for the production of a varied line of nonferrous castings. A uniform grade of molding sand makes practical the use of a single sand-handling unit.

(2) That unjacketed molds can be safely moved on roller conveyors into position for pouring.

(3) That metal of high quality can be produced in an electric arc furnace from a melting stock compounded of scrap materials.

(4) That small lots of castings can be cleaned rapidly in tumbling barrels of special design.

DISCUSSION

ORAL DISCUSSION

B. F. MCAULEY: The handling method used in the brass foundry at the Hawthorne Works of the Western Electric Co., may be of interest because of the type and diversity or variety of the product required in the every-day use of the telephone, the castings for which, in general, must be small. However, castings which are somewhat larger are used also on telephone apparatus, sound picture and teletype equipment. All in all, the copper-base castings average in weight from one ounce to seven pounds; the aluminum castings, from one-half pound to approximately fifteen pounds.

When consideration was given to sand handling and continuous pouring, its application at first was considered somewhat impractical. It had always been thought that, with our diversified product, different pouring conditions and several grades of sand were required. After investigation, however, we found that a sand approximating No. 2 A. F. A. grade was entirely satisfactory for all grades of brass and aluminum castings. Also, this simplified the sand problem and made possible the use of the single sand-handling unit.

Another factor that had to be considered was the large number of patterns in our stock, which included several thousand metal patterns, all of which were end-gated and used with snap flasks. We started in to work on the layout and design of a system that would accommodate our various patterns and flasks. After the preliminary design had been completed, estimates were made as to the cost of installation and possible economies that might be effected in production costs. The picture was rather pleasing and the indications were that the cost of installation

would pay for itself within a satisfactory period of time. Authorization then was granted to proceed with the installation.

With our former brass foundry, the molders, after making the molds, were required to pour them; our scrap was averaging approximately eight per cent. Since the introduction of the present system we have doubled our capacity in the same area and have reduced our scrap to approximately four per cent.

MEMBER: What is the sand temperature at the close of the day? Do you find much increase on account of the comparatively short conveyor methods you employ?

D. G. ANDERSON: Our castings being small, there is very little increase in the temperature of the sand, and we have had no trouble from that cause. Sands do become hot in hoppers that are square, and perhaps even when tapered. Then there is a small stream of hot sand running through the center of the hopper. Where the hopper, as in our system, is smaller on the top than the bottom, the column area of sand forces the whole weight of the sand down evenly, and we get no hot sand.

MEMBER: In adding water to the sand, is that done automatically or by an operator?

B. F. MCAULEY: It is done by an operator. We have a resistance meter which indicates very closely the moisture content of the sand.

MEMBER: How hot could the sand be and still be usable in the molds?

E. W. BEACH:¹ In our iron foundry we frequently made tests which showed that the sand, sometimes late in the afternoon, ran as high a temperature as 170 degrees at the shakeout. We do not like to use sand in the molds when hotter than 100 or 110 degrees maximum. We try to reduce the temperature by sufficient aeration, down to 100 degrees at least, but at times we have difficulty in doing this.

D. G. ANDERSON: In our nonferrous foundry I believe it is to our disadvantage if the temperature of the sand exceeds the room temperature to any great extent, for then it will stick to the patterns. I think that 100 degs. Fahr. is perhaps on the border line of being too high.

E. W. BEACH: One belt conveyor I have in mind serves ten small units and rehandles 60 tons of sand six times in eight hours. They are all heavy mechanical producing units, and at peak production it is necessary to add cold sand to the facing mixture, as it is a dual system providing facing sand and backing sand to each pair of machines. We have to increase the amount of facing sand in each mold, which of course creates an excessive sand cost. We add the extra weight of facing sand simply to hold the heat of the backing sand from drying out the face of the mold; but we seldom use sand hotter than 110 degrees in normal operation. Room temperature is desirable and a great advantage.

MEMBER: I have been led to believe that it is bad practice to drag the sand along the conveyor surface. Have you had any trouble from that cause?

¹Engineering Executive, Campbell, Wyant & Cannon Foundry Co., Muskegon, Mich.

D. G. ANDERSON: Because of statements which had been made to us, I investigated this point very carefully. I visited plants having successful systems in operation, and my observations were that the sand does not form balls as it drags along. I prefer the drag conveyor system principally because it is automatic and the sand does not dry out as quickly as in other types.

Another point concerning the drag conveyor which is questioned, is that there may be a thin layer of sand on the bottom that the flights do not touch, and it is thought that this sand will dry out overnight, causing dry sand flakes in the sand the next day. By adding a rubber wiper to these flights, we scrape the sand free from the bottom, giving us a clean conveyor all day.

H. L. MCKINNON:² I believe that the factor of speed has led to a distrust of the belt method as a whole. Nearly twenty years ago we found that sand could be carried on a belt and impinged against a plow with the same resulting damage as on a flight conveyor, provided the speed is great enough. We have found that somewhere around 100 feet per minute is the danger point; that the sand, especially if well tempered, has a tendency to roll in balls which are very liable to mar the face of the casting if it comes against the pattern.

By limiting the speed of flight conveyors or by supplying sand from a belt, the quality can be maintained and the balling action reduced to a minimum. That is the principle at stake in this whole problem, I believe.

B. F. MCAULEY: The conveyor described operates at 40 ft. per minute.

B. D. FULLER:³ In confirmation of what Mr. McKinnon has said, I recall a conveyor with which I had an interesting experience twenty-five years ago. The operators were throwing away half a carload of perfectly good sand a day because of balling. The conveyor had a reciprocal drag; in other words, it moved forward fifteen or eighteen inches and then dragged back over the sand. It ran rather fast.

Engineers were set on the problem. They installed rolls, passed the balls through the rolls and tried to mash them up, and in other ways they did everything they could to overcome the balling trouble. Finally, one day the conveyor broke down. When it was started up again it was run for a day or two at twenty-five per cent of the ordinary speed, and the trouble disappeared at once.

MEMBER: Do the authors use facing sand in addition to system sand?

D. G. ANDERSON: When we do, we serve it in pans. It is used only on castings where the surface finish is exacting.

CHAIRMAN D. M. AVEY:⁴ At what point do you take the sample of sand for control?

D. G. ANDERSON: From the molders' hoppers. We check by the resistance method for moisture at the mixer. At first we took samples at various points in the system to see what drop there would be in the

² Secretary, C. O. Bartlett & Snow Co., Cleveland.

³ Sales Representative, Whitehead Bros. Co., Lakewood, Ohio.

⁴ Penton Publishing Co., Cleveland.

moisture from the conveyor, etc., but now we get it from the molders' hoppers, as that is where we want the optimum properties.

MEMBER: Do you have any trouble in protecting your intricate castings from little run-offs on the side of the castings due to the sand falls from a gate?

D. G. ANDERSON: We do at times. Especially with perpendicular surfaces do we get a run-off, but that is corrected by hand tamping or else by placing the riddle over the flask as the sand is dropped.

MEMBER: What are the weights of the castings?

B. F. MCAULEY: The individual brass castings range from one ounce to seven pounds; the aluminum castings, from one-half pound to fifteen pounds.

MEMBER: Approximately what is the ratio of sand to metal poured in each mold?

D. G. ANDERSON: A rough approximation for the average weight of our molds is perhaps sixty pounds. The average weight of our brass castings is perhaps not over ten pounds.

One point I would like to mention in connection with this handling of sand, and bearing on the ratio of sand to metal, is the difficulty of getting sand that flows. It is very nearly necessary to have the bin larger at the bottom than at the top. That is something I consider very essential in handling molding sand when the temperature of sand is a question.

M. W. PORRS:² At a materials handling session four or five years ago in Philadelphia, there seemed to be lacking among the foundrymen any desire to contribute information to the handling engineer that would assist him in selling them a real guide. They left it up to the engineer to do the entire job. He knew little about the foundry business and consequently went through a terrific strain trying to figure things out. It gives me a great deal of pleasure to be present here and see such cooperation between the mechanical engineer and the foundryman in solving the problems of materials handling in the foundry.

² Sales Engineer, Alvey-Ferguson Co., New York, and secretary, A. S. M. E. Materials Handling Division.

Some Thoughts Concerning Mixtures, The Perlit Process and the Heat Treatment of Cast Iron*

By HORACE J. YOUNG, LONDON, ENGLAND

Abstract

In the author's experience, practically every type of casting produces some problem of interest and is well worthy of study. For this paper, he picks out three to be given consideration, first, the numerous mixtures which can be made from a stockyard containing four pig irons, steel and scrap, to produce a given analysis. The characteristics of a series are discussed from the standpoint of price and satisfactory results. Secondly, he discusses what can be accomplished by the perlit or hot-mold process in comparison with cold-mold results. The third proposition discussed is heat treatment. Possibilities of heat treatment are given, and photomicrographs of heat-treated irons are shown.

1. The author has had wide experience in many foundries with such castings as propellers, diesel cylinder heads, liners, skirts, turbine castings, reciprocating engine cylinders, cylinder liners for superheated steam, mono-block cylinders for light-draft gunboats, valves, castings for low-temperature carbonization plants, economizer tubes and plugs, locomotive and automobile castings, pistons, pots, liners, rings, light castings and pipes, wheels, rams, etc. Each of these constitutes a problem of interest to someone.

2. Different people are interested in different problems, such as a soil pipe as good as new after fifty years service; a diesel cylinder head cracked in three months; an economizer plug graphitized and being graphitized more every year; a fire bar which outlasted ten similar bars of a different cast iron; the single-cast piston ring process where a casting enters the machine shop weigh-

* Exchange paper presented on behalf of the Institute of British Foundrymen.

NOTE: This paper was presented before one of the gray iron sessions at the 1932 convention of the American Foundrymen's Association.

Table 1
ANALYSES AND COSTS OF IRONS IN STOCK YARD

	C	Si	P	S	Mn	Cost,* incl. freight
Phosphoric Pig A	3.6	2.5	1.2	0.04	0.5	89
Phosphoric Pig B	3.5	1.2	1.2	0.05	0.5	86
Hematite Pig C	4.5	2.5	...	0.03	1.0	99
Hematite Pig D	4.2	1.2	...	0.04	1.0	95
Scrap Iron	3.4	1.8	0.8	0.10	0.6	79
Steel Scrap	0.05	0.05	0.05	0.03	0.4	68
Ferromanganese	6.5	...	...	...	80.0	319

* Costs in Tables 1-20, inclusive, assumed as shillings per ton (2240 lbs.)

ing about $\frac{3}{4}$ ounce and weighs less than half that when machine finished, turned out in tens of thousands daily.

3. Searching, however, for problems of general interest, the author has prepared the material in this paper for the following reasons: First, mixtures—because every separate mixture is approved by some foundryman; secondly, the perlit process—because this process has added definitely to the knowledge of foundry products; third, heat treatment of cast iron—because this is a fertile field which may bring 80-ton iron of great density, machinable as desired and without necessitating expensive alloying elements.

MIXTURES

4. If ignorance, slovenliness or carelessness are to be found anywhere in a foundry, usually it begins in the stock yard and ends in the molds, the machine shops and the testing room, and it is apt to pervade a firm's entire manufacturing operations. For the purposes of this paper, however, it is assumed that the foundry has a satisfactory stock yard containing the materials listed in Table 1 at arbitrary cost figures. Each foundryman may fill in materials, compositions and prices to comply with his own ideas and requirements.

5. The stock yard, thus assumed as set out in Table 1, gives us the cost of the irons, including freight charges. The latter is a difficult item to include, inasmuch as some foundrymen buy the irons near their operations, while others prefer to purchase from distant points.

6. Let us assume that we desire to charge into our cupolas a mixture containing 1.7 per cent silicon, 0.7 per cent phosphorus and 0.8 per cent manganese. How shall we do it? How many

Table 2

MAXIMUM SCRAP WITH NO STEEL

	C	Si	P	S	Mn	Cost
90 parts Scrap Iron	3.06	1.62	0.72	0.11	0.54	71.10
10 parts Hematite <i>D</i>	0.42	0.12	....	....	0.10	9.50
100 (plus 5 lbs. ferromanganese per ton)					0.18	0.71
	3.48	1.74	0.72	0.11	0.82	81.31

Table 3

HALF SCRAP WITH NO STEEL

	C	Si	P	S	Mn	Cost
50 parts Scrap Iron	1.70	0.90	0.40	0.06	0.30	39.50
30 parts Phosphoric Pig <i>B</i>	1.05	0.36	0.36	0.02	0.15	25.80
15 parts Hematite <i>C</i>	0.68	0.37	....	0.01	0.15	14.85
5 parts Hematite <i>D</i>	0.21	0.06	....	....	0.05	4.75
100 (plus 5 lbs. ferromanganese per ton)				....	0.18	0.71
	3.64	1.69	0.76	0.09	0.83	85.61

Table 4

HALF SCRAP WITH NO STEEL

	C	Si	P	S	Mn	Cost
50 parts Scrap Iron	1.70	0.90	0.40	0.05	0.30	39.50
10 parts Phosphoric Pig <i>B</i>	0.35	0.12	0.12	0.05	0.05	8.60
20 parts Phosphoric Pig <i>A</i>	0.72	0.50	0.24	0.01	0.10	17.80
20 parts Hematite <i>D</i>	0.84	0.24	0.06	0.01	0.20	19.00
100 (plus 5 lbs. ferromanganese per ton)					0.18	0.71
	3.61	1.76	0.76	0.12	0.83	85.61

ways can this be done using only the four pig irons, and the scrap and steel if necessary? Will each method give the same result? Which suitable mixture will be the cheapest?

7. A few of the more simple charges are tabulated in Tables 2-20, inclusive. Table 2 gives a mixture with maximum scrap and no steel. This mixture is likely to go high in sulphur and to make a brittle iron of low quality and low price. Table 3 shows a mixture of half scrap with no steel, and is better than the previous mixture. It does not contain so much scrap, but it is more expensive. A mixture much cheaper than this and without the

Table 5

QUARTER SCRAP WITH NO STEEL

	C	Si	P	S	Mn	Cost
25 parts Scrap Iron	0.85	0.45	0.20	0.03	0.15	19.75
40 parts Phosphoric Pig <i>B</i>	1.40	0.48	0.48	0.02	0.20	34.40
30 parts Hematite <i>C</i>	1.35	0.75	0.00	0.01	0.30	29.70
5 parts Hematite <i>D</i>	0.21	0.06	0.00	0.00	0.05	4.75
100 (plus 3 lbs. ferromanganese per ton)				....	0.11	0.44
	3.81	1.74	0.68	0.06	0.81	89.04

Table 6

QUARTER SCRAP WITH NO STEEL

	C	Si	P	S	Mn	Cost
25 parts Scrap Iron	0.85	0.45	0.20	0.03	0.15	19.75
30 parts Phosphoric Pig <i>A</i>	1.08	0.75	0.36	0.01	0.15	26.70
10 parts Phosphoric Pig <i>B</i>	0.35	0.12	0.12	0.01	0.05	8.60
35 parts Hematite <i>D</i>	1.47	0.42	0.00	0.01	0.35	32.25
100 (plus 3 lbs. ferromanganese per ton)				....	0.11	0.44
	3.75	1.74	0.68	0.06	0.81	87.74

Table 7

NEITHER SCRAP NOR STEEL

	C	Si	P	S	Mn	Cost
40 parts Phosphoric Pig <i>A</i>	1.44	1.00	0.48	0.02	0.20	35.60
20 parts Phosphoric Pig <i>B</i>	0.70	0.24	0.24	0.01	0.10	38.00
40 parts Hematite <i>D</i>	1.68	0.48	0.00	0.02	0.40	17.20
100 (plus 3 lbs. ferromanganese per ton)				....	0.11	0.44
	3.82	1.72	0.72	0.05	0.81	91.24

Table 8

NEITHER SCRAP NOR STEEL

	C	Si	P	S	Mn	Cost
30 parts Phosphoric Pig <i>A</i>	1.08	0.75	0.36	0.01	0.15	26.70
30 parts Phosphoric Pig <i>B</i>	1.05	0.36	0.36	0.02	0.15	25.80
10 parts Hematite <i>C</i>	0.45	0.25	0.00	0.00	0.10	9.90
30 parts Hematite <i>D</i>	1.26	0.36	0.00	0.01	0.30	28.50
100 (plus 3 lbs. ferromanganese per ton)				....	0.11	0.44
	3.84	1.72	0.72	0.04	0.81	91.34

Table 9

NEITHER SCRAP NOR STEEL

	C	Si	P	S	Mn	Cost
20 parts Phosphoric Pig A	0.72	0.50	0.24	0.01	0.10	17.80
40 parts Phosphoric Pig B	1.40	0.48	0.48	0.02	0.20	34.40
20 parts Hematite C	0.90	0.50	0.00	0.01	0.20	19.80
20 parts Hematite D	0.88	0.24	0.00	0.01	0.20	19.00
100 (plus 3 lbs. ferromanganese per ton)				....	0.11	0.44
	3.90	1.72	0.72	0.05	0.81	91.44

Table 10

NEITHER SCRAP NOR STEEL

	C	Si	P	S	Mn	Cost
60 parts Phosphoric Pig B	2.10	0.72	0.72	0.03	0.30	51.60
40 parts Hematite C	1.80	1.00	0.00	0.01	0.40	39.60
100 (plus 3 lbs. ferromanganese per ton)				....	0.11	0.44
	3.90	1.72	0.72	0.04	0.81	91.64

Table 11

30 PER CENT (MAXIMUM) STEEL WITH MAXIMUM SCRAP

	C	Si	P	S	Mn	Cost
10 parts Scrap Iron	0.34	0.18	0.08	0.01	0.06	7.90
50 parts Phosphoric Pig A	1.80	1.25	0.60	0.02	0.25	44.50
10 parts Hematite C	0.45	0.25	0.00	0.00	0.10	9.90
30 parts Steel	0.01	0.01	0.01	0.01	0.12	20.40
100 (plus 8 lbs. ferromanganese per ton)				....	0.29	1.15
	2.60	1.69	0.69	0.04	0.82	83.85

softening influence of the high-silicon hematite, if such be desired, is given in Table 4.

8. A mixture of quarter scrap with no steel is given in Table 5. This is a high-carbon mixture influenced to large graphite by the high-silicon cementite. The mixture of Table 6, also quarter scrap with no steel, is slightly cheaper than the previous mixture and not so likely to be open-structured.

Mixtures with No Scrap or Steel

9. A mixture with neither scrap or steel is given in Table 7. It is probably the closest iron possible with an all-pig mixture

Table 12

30 PER CENT (MAXIMUM) STEEL WITH NO SCRAP

	C	Si	P	S	Mn	Cost
60 parts Phosphoric Pig A	2.16	1.50	0.72	0.02	0.36	53.40
5 parts Hematite C	0.22	0.12	0.00	0.00	0.05	4.95
5 parts Hematite D	0.21	0.06	0.00	0.00	0.05	4.75
30 parts Steel	0.01	0.01	0.01	0.01	0.12	20.40
100 (plus 8 lbs. ferromanganese per ton)				....	0.29	1.15
	2.60	1.69	0.73	0.03	0.81	84.65

Table 13

20 PER CENT STEEL WITH MAXIMUM SCRAP

	C	Si	P	S	Mn	Cost
40 parts Scrap Iron	1.36	0.72	0.32	0.04	0.24	31.60
30 parts Phosphoric Pig A	1.08	0.75	0.36	0.01	0.15	28.70
10 parts Hematite C	0.45	0.25	0.00	0.00	0.10	9.90
20 parts Steel	0.01	0.01	0.01	0.01	0.08	13.60
100 (plus 7 lbs. ferromanganese per ton)				....	0.25	1.00
	2.90	1.73	0.69	0.06	0.82	82.80

of these particular irons. Table 8 gives another mixture, much the same as that of Table 7 but incorporating some high-silicon hematite. Tables 9 and 10 also are no-scrap, no-steel mixtures, with Table 9 having still more high-silicon hematite and higher carbon. Table 10 gives the maximum of high-silicon hematite with consequent high carbon and a tendency to large graphite.

Maximum Steel Mixtures

10. A mixture with maximum steel and maximum scrap is shown in Table 11. Probably this would make the strongest iron of the series, and it is one of the cheapest. Table 12 shows a mixture with maximum steel but no scrap. It is not dissimilar to the previous mixture, but it is a little more costly.

20 Per Cent Steel Mixtures

11. A 20 per cent steel with maximum scrap is shown in Table 13. This would be a very usable steel mix and is hardly more costly than that mixture containing 90 per cent scrap iron. A 20 per cent steel mixture with no scrap is that of Table 14. It is more expensive than the previous mixture but probably is an

easier one to use (although, of course, there are other intermediate and similar mixtures using less than 40 per cent scrap which are not given here).

12. Table 15 also is a 20 per cent steel with no scrap mixture, using all high-silicon hematite. The same remarks apply to the mixture shown in Table 14.

10 Per Cent Steel Mixtures

13. Tables 16 to 20, inclusive, are for 10 per cent steel mixtures with varying scrap. Table 16, with maximum scrap, prob-

Table 14

20 PER CENT STEEL WITH NO SCRAP

	C	Si	P	S	Mn	Cost
60 parts Phosphoric Pig A	2.16	1.50	0.72	0.02	0.30	53.40
20 parts Hematite D	0.84	0.24	0.00	0.01	0.20	19.00
20 parts Steel	0.01	0.01	0.01	0.01	0.08	13.60
100 (plus 6 lbs. ferromanganese per ton)				....	0.22	0.88
	3.01	1.75	0.73	0.04	0.80	86.88

Table 15

20 PER CENT STEEL WITH NO SCRAP

	C	Si	P	S	Mn	Cost
35 parts Phosphoric Pig A	1.26	0.87	0.42	0.01	0.17	31.15
25 parts Phosphoric Pig B	0.87	0.30	0.30	0.01	0.12	21.50
20 parts Hematite C	0.90	0.50	0.00	0.01	0.20	19.80
20 parts Steel	0.01	0.01	0.01	0.01	0.08	13.60
100 (plus 7 lbs. ferromanganese per ton)				....	0.25	1.00
	3.04	1.68	0.73	0.04	0.82	87.05

Table 16

10 PER CENT STEEL WITH MAXIMUM SCRAP IRON

	C	Si	P	S	Mn	Cost
80 parts Scrap	2.72	1.44	0.64	0.08	0.48	53.20
5 parts Phosphoric Pig A	0.18	0.12	0.06	0.00	0.02	4.45
5 parts Hematite C	0.22	0.12	0.00	0.00	0.05	4.95
10 parts Steel	0.00	0.00	0.00	0.00	0.04	6.80
100 (plus 3 lbs. ferromanganese per ton)				....	0.11	0.44
	3.12	1.68	0.70	0.08	0.70	79.84

Table 17

10 PER CENT STEEL WITH HALF SCRAP IRON

	C	Si	P	S	Mn	Cost
50 parts Scrap	1.70	0.90	0.40	0.05	0.30	39.50
10 parts Phosphoric Pig A	0.36	0.25	0.12	0.00	0.05	8.90
15 parts Phosphoric Pig B	0.52	0.18	0.18	0.01	0.07	12.90
15 parts Hematite C	0.67	0.37	0.00	0.00	0.15	14.85
10 parts Steel	0.00	0.00	0.00	0.00	0.04	0.80
100 (plus 3 lbs. ferromanganese per ton)				....	0.11	0.44
	3.25	1.70	0.70	0.06	0.72	77.39

Table 18

10 PER CENT STEEL WITH HALF SCRAP IRON

	C	Si	P	S	Mn	Cost
50 parts Scrap	1.70	0.90	0.40	0.05	0.30	39.50
25 parts Phosphoric Pig A	0.90	0.62	0.30	0.01	0.12	22.25
15 parts Hematite D	0.63	0.18	0.00	0.01	0.15	14.25
10 parts Steel	0.00	0.00	0.00	0.00	0.04	6.80
100 (plus 3 lbs. ferromanganese per ton)				....	0.11	0.44
	3.23	1.70	0.70	0.07	0.72	83.24

Table 19

10 PER CENT STEEL WITH QUARTER SCRAP IRON

	C	Si	P	S	Mn	Cost
25 parts Scrap	0.85	0.45	0.20	0.03	0.15	19.75
35 parts Phosphoric Pig A	1.26	0.87	0.42	0.01	0.17	31.15
5 parts Phosphoric Pig B	0.17	0.06	0.06	0.00	0.02	4.30
25 parts Hematite D	1.05	0.30	0.00	0.01	0.25	23.75
10 parts Steel	0.00	0.00	0.00	0.00	0.04	6.80
100 (plus 2 lbs. ferromanganese per ton)				....	0.07	0.29
	3.33	1.68	0.68	0.05	0.70	86.04

Table 20

10 PER CENT STEEL WITH QUARTER SCRAP IRON

	C	Si	P	S	Mn	Cost
25 parts Scrap	0.85	0.45	0.20	0.03	0.15	19.75
10 parts Phosphoric Pig A	0.36	0.25	0.12	0.00	0.05	8.90
30 parts Phosphoric Pig B	1.05	0.36	0.36	0.02	0.15	25.80
25 parts Hematite C	1.12	0.62	0.00	0.01	0.25	24.75
10 parts Steel	0.00	0.00	0.00	0.00	0.04	6.80
100 (plus 2 lbs. ferromanganese per ton)				....	0.07	0.29
	3.38	1.68	0.68	0.06	0.71	86.29

ably is an unsatisfactory mixture because it is ruled too strongly by scrap and is likely to rise in sulphur. The mixture of Table 17, with half scrap iron, might be a good mixture for heavy castings and is very cheap.

14. Another half scrap mixture with 10 per cent steel is that of Table 18. Probably this would be a closer iron than that of Table 17, owing to the use of low-hematite pig. It should also be a good mixture for heavy castings and is very cheap. The mixture of Table 19 is one with 10 per cent steel and a quarter scrap iron. As the amount of scrap is lowered, the iron becomes more plastic and more readily kept to standard.

15. The mixture of Table 20, while similar to that of Table 19, in all probability would give a softer and more graphitic iron. Thus, it is demonstrated how mixtures of similar silicon, phosphorus and manganese content may be made in great variety from a stock yard containing only four pig irons. It will depend on the qualities required in the castings produced as to which of these mixtures is the better for the purpose.

16. We may require a soft iron free from internal stresses, or a soft iron of an impenetrable nature, or iron of high tensile, or one to take sharp impressions from the mold, or to machine quickly and easily, or to resist dry abrasion or lubricated wear, or to withstand shocks, or to possess a good skin when leaving the mold, or to tin or enamel well, or to possess plenty of "spring," or to be little affected by variations in casting thickness, and so on. With such variations in demand, it is small wonder that the mixing of irons for cupola use is a world-wide problem.

17. Moreover, the variety of mixtures opens up a great field for the reduction of foundry costs. In the author's country there are foundries buying the cheapest chaplets who yet are spending many shillings a ton on irons unnecessarily expensive or purchased from a greater distance than is necessary.

THE PERLIT PROCESS

18. The metallurgy of perlit cast iron is that of ordinary cast iron reversed. For example, a wedge-shaped piece of iron, under ordinary conditions, is white at the thin part and very gray in the center of the thick section. Under perlit conditions this would be entirely reversed.

Table 21

Iron	Thickness of Cast Plate, inches	Type of Mold	Nature of Iron Nearer to Mold Surfaces	Nature of Iron in Center of Section	Remarks
A	5	Cold dry-sand.	Slightly ferritic.	Very ferritic.	It will be seen that the iron in center of the section has remained unaffected by any of the treatments, but that each of the mold surfaces. Only the heated mold makes the iron the same throughout the section.
A	5	Cold dry-sand with light chill on each side (i. e., denser).	All pearlitic.	Very ferritic.	
A	5	Cold dry-sand, slightly heavier chills.	Rather cementitic.	Very ferritic.	
A	5	Heated dry-sand, (i. e., loaded with heat units).	Very ferritic.	Very ferritic.	Here again, the iron is unaffected in the center of its section by any of the treatments, but the heated mold makes the outside parts similar to the inside.
A	3	Cold dry-sand.	All pearlitic.	Slightly ferritic.	
A	3	Cold dry-sand with light chill on each side.	Rather cementitic.	Slightly ferritic.	
A	3	Cold dry-sand, slightly heavier chills.	Very cementitic.	Slightly ferritic.	Here again, the iron is unaffected in the center of its section by any of the treatments, but the heated mold makes the outside parts similar to the inside.
A	3	Heated dry-sand.	Slightly ferritic.	Slightly ferritic.	
A	1	Cold dry-sand with light chill on each side.	Rather cementitic.	All pearlitic.	
A	1	Cold dry-sand, slightly heavier chills.	Inclined to be white.	All pearlitic.	Here all four treatments affect the center of section as well as the outside, and heated mold makes the iron all-pearlitic throughout.
A	1	Heated dry-sand.	All pearlitic.	All pearlitic.	
A	1/4	Cold dry-sand.	Inclined to be white.	Very cementitic.	
A	1/4	Cold dry-sand, with light chill on each side.	White.	Inclined to be white.	
A	1/4	Cold dry-sand, slightly heavier chills.	White.	White.	
A	1/4	Heated dry-sand.	All pearlitic.	All pearlitic.	

Table 21—Continued

IRON	Thickness of Cast Plate, inches	Type of Mold	Nature of Iron Nearer to Mold Surfaces	Nature of Iron in Center of Section.	Remarks
B	3	Cold dry-sand.	Very cementitic.	All pearlitic.	} Both treatments affect only those portions near to the mold surface.
B	3	Heated dry-sand.	All pearlitic.	All pearlitic.	
B	2	Cold dry-sand.	Inclined to be white.	All pearlitic.	
B	2	Heated dry-sand.	All pearlitic.	All pearlitic.	} Both treatments affect only those portions near to the mold surface.
B	1	Cold dry-sand.	White.	All pearlitic.	
B	1	Heated dry-sand.	All pearlitic.	All pearlitic.	
B	$\frac{1}{2}$	Cold dry-sand.	White.	Very cementitic.	} At this thickness both treatments affect the inside as well as the outside.
B	$\frac{1}{2}$	Heated dry-sand.	All pearlitic.	All pearlitic.	
B	$\frac{1}{4}$	Cold dry-sand.	White.	White.	
B	$\frac{1}{4}$	Heated dry-sand.	All pearlitic.	All pearlitic.	} At this thickness both treatments affect the inside as well as the outside.
C	3	Cold dry-sand.	Inclined to be white.	Very cementitic.	
C	3	Heated dry-sand.	All pearlitic.	Very cementitic.	
C	1	Cold dry-sand.	White.	Very cementitic.	} Only the outside surface affected.
C	1	Heated dry-sand.	All pearlitic.	Very cementitic.	
C	$\frac{1}{4}$	Cold dry-sand.	White.	White.	
C	$\frac{1}{4}$	Heated dry-sand.	All pearlitic.	All pearlitic.	} Inside as well as outside surface affected.

19. Stupendous obstacles prevent proof of the advantages of the process by merely describing the method. Accordingly, an attempt is made here to demonstrate the process logically by examples of what foundrymen know to be true of cast iron, together with what perlit makers know is true of perlit iron.

20. In Table 21, the irons *A*, *B* and *C* are irons which in a cold dry-sand mold behave as shown, and which when (a) lightly chilled, or (b) slightly chilled, or (c) cast in a heated mold (that is, in a mold containing many heat units), also behave as shown. From these examples it is possible to summarize the process step by step.

21. The cooling effect of a mold depends on the surface area of the sand in relation to the volume of the iron between the sand faces. For example, a plate 5 in. thick has no more surface area to cool than has a plate $\frac{1}{4}$ in. thick. Hence, in the case of the 5-in. plate the iron is affected to a small depth only, while the iron in the $\frac{1}{4}$ -in. plate is affected clear to the center. Therefore, it follows that the cold sand mold will make the $\frac{1}{4}$ -in. plate white throughout, while the heated sand mold will keep it gray throughout.

22. If we consider an iron that is white all through when cast at 3 in. thickness in a cold dry-sand mold, that iron will be gray outside and white inside when heated in a dry-sand mold. This will persist for varying section thicknesses until it is cast at such thin sections that the effect of the heated mold can penetrate to the center, when the iron will be gray throughout.

23. However, if we take an iron that is all-pearlitic only at the center of the thickest section—for example, 3 in. thickness—when cast in a cold dry-sand mold, the heated mold will make the outside part of the section also all-pearlitic instead of cementitic (as in the case of the cold dry-sand mold). Moreover, as the section thicknesses decrease, the surface areas of the sand in contact with them increase. Thus, the cold mold increasingly tends to make the iron less like it was at the center of the 3-in. section, whereas the hot mold does the very opposite, namely, tends to keep it the same as at the center.

24. That phenomenon known as inverse chill is produced easily by anyone desiring to adopt perlit principles. One has only to take an iron white all through when cast at, say, 3 in.

thickness in a cold mold, and it will be found that the iron is gray outside and white inside when cast at the same thickness in a heated mold.

25. When molten iron is poured into a cold mold, the surfaces of the mold promptly begin to convey heat away from the iron so that a thin section (having large surface) is chilled and cooled quickly. However, if the mold already contains a large number of heat units, it is no longer in a condition to take on any more readily, with the result that the cooling of thinner sections is delayed by the large surface area of the sand around them and to a greater degree than is the case with cooling of the thicker sections.

26. One thing in particular may be accomplished through the use of perlit methods which, so far as the author knows, cannot be done in any other way. Gray castings can be made of iron which, if cast in cold molds, would give white iron castings. Iron of 0.4 per cent silicon content can be used, and there is no scientific reason to suppose that iron of 0.8 per cent silicon could not be used, although it might be commercially impracticable.

27. This is to say that gray heat-resisting castings can be produced having fine machining properties and with great strength and resistance to impact, by means of the perlit process.

28. With reference to resistance to impact, it has been found that the repeated impact test of the fatigue type is comparatively useless for gray iron containing flaky graphite. On the other hand, the heavy and genuine impact test is highly discriminating. During the past three years perlit manufacturers in England have been testing hundreds of qualities of cast iron, semi-steel, alloy iron, etc., by means of the heavy impact test, and it has been a matter almost of competition as to who could produce an iron giving a result anywhere near as good as those irons constantly obtained under Perlit conditions.

HEAT TREATMENT OF CAST IRON

29. No effort is made in this paper to discuss heat treatment beyond a few outstanding points, as follows:

(a) No heat treatment which deteriorates the graphite is of any use, no matter how greatly it improves or alters the structure of the metal. The photomicrographs presented here (Figs. 1-9,

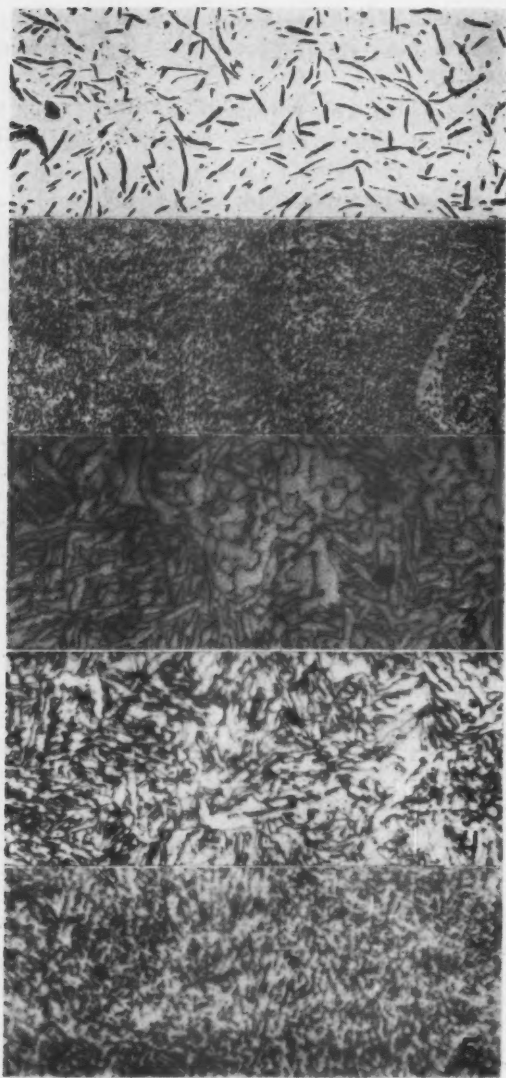


FIG. 1.—GRAPHITE STRUCTURE REMAINS UNALTERED IN ALL SPECIMENS, HEAT TREATED OR NOT. X25. FIG. 2—HEAT TREATED IRON. X400. FIG. 3—HEAT TREATED IRON. X1500. FIG. 4—HEAT TREATED IRON. X1500. FIG. 5—HEAT TREATED IRON. X1500.

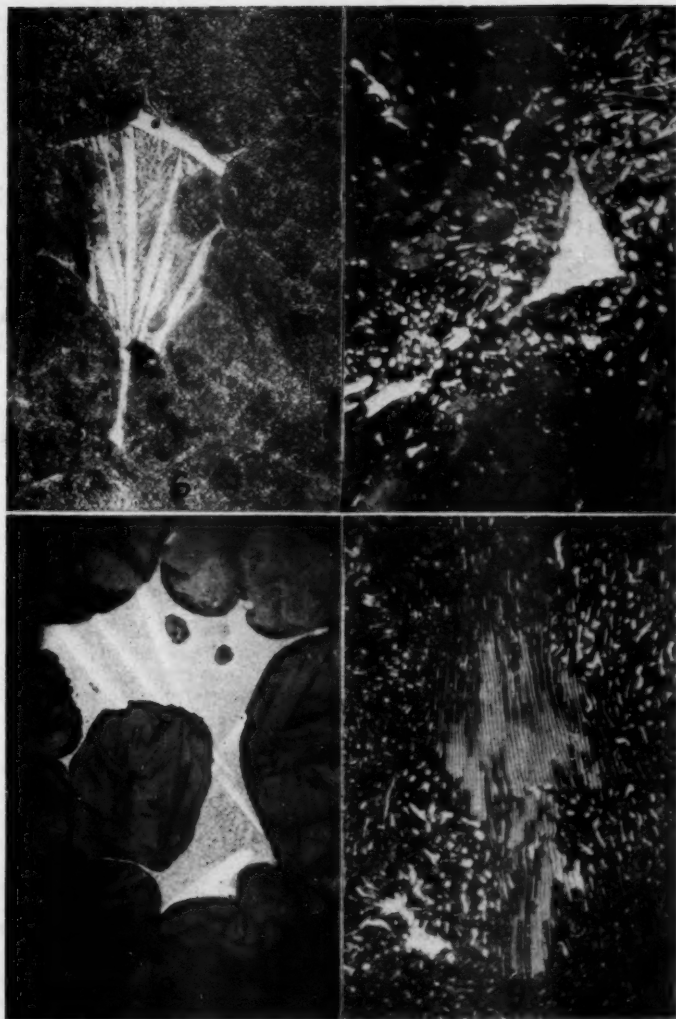


FIG. 6—HEAT TREATED IRON. A PHOSPHIDE EFFECT. X400. FIG. 7—HEAT TREATED IRON. A PHOSPHIDE EFFECT. X1500. FIG. 8—HEAT TREATED IRON. A PHOSPHIDE EFFECT. X400. FIG. 9—HEAT TREATED IRON. A PHOSPHIDE EFFECT. X1500.

inclusive) have been selected from dozens of efforts, none of which changed the graphite in either direction.

(b) Through heat treatment it was possible to double the Brinell hardness of iron without altering its machinability or its fracture. How this will affect its wearing qualities has yet to be discovered.

(c) Through heat treatment the tensile strength was doubled, the iron remaining as machinable as before. There was no good reason to suppose that intensive research would not treble or even quadruple the tensile properties. This may prove impossible, of course, but no evidence is available that such is the case.

(d) An immense variety of structures was produced with certainty and ease.

(e) The practical applications of the procedure were not investigated, but that they are good is not to be doubted, particularly for smaller castings up to, say, 28 lbs. in weight.

DISCUSSION

WRITTEN DISCUSSION

JOHN SHAW:* I have read Mr. Young's paper with a good deal of enjoyment. It cannot be said that he leaves the reader without matter for discussion. From his stock yard he evolves a series of mixtures to suit all requirements.

Unfortunately, it is not stated to which type of casting each mixture is suitable, and the whole savors very much of the easy, popular crossword puzzle wherein each clue has a dozen alternatives and it is only by luck that one picks the winner. One thing, however, is clear, namely, that Mr. Young now has some belief in heredity, at all events when dealing with cupola metal, and that the ordinary chemical analysis does not entirely dominate the situation.

On the question of perlit iron, Mr. Young has a wide experience with

* Southsea, England.

this process. His logical examples give fundamental reasons (some of which, however, are open to criticism), but he does not enter into details of the advantages, difficulties or limitations of the method that would enable foundrymen to see how far it could be applied to their own product.

The effect of the hot mold on the structure of the resultant casting has been known for many years. The writer remembers a firm of locomotive engine makers who, as far back as 1912, in order to cast both their heavy and light cylinders from one mixture, closed the latter and placed it in the hot stove until the metal was ready.

Although the effect of heated molds was thus roughly known, full credit must be given to Diefenthaler and the Lanz company for developing the plan and placing it on a scientific and controlled basis. The original specification gives "particular temperatures for heating dry-sand molds for iron castings of specified thickness and composition." Thus a composition of 3 per cent total carbon is recommended, of which 0.85 per cent is combined together with 1 per cent silicon, 0.7 per cent manganese, 0.1 per cent sulphur, 0.4 per cent phosphorus, and for this the molds require heating to 390 degs. Fahr. for a thickness of 0.4 in., or 300 degs. Fahr. for 0.8 in., or 210 degs. Fahr. for 1.2 in.

The chief advantage of the process undoubtedly lies in the fact that, for the same thickness of castings, one can reduce the silicon according to the temperature of the mold and thus obtain a more homogeneous structure than from a cold mold with its higher silicon. How far Mr. Young's suggestion is true that, owing to the hot mold there is a slight "hesitation" during which everything has a chance to level up, is not known. The lower silicon also lessens the tendency to grow.

How far this is worth the extra cost, or whether the same effect can be obtained with alloy additions or inoculations such as calcium silicide, is for each foundryman to decide for himself.

Many foundrymen fight shy of closing and then restoring their molds to the stove and doubts are also expressed as to maintaining the correct temperatures if casting is delayed. From what I have seen, little difficulty is experienced providing there is not too much variation in the thickness of various castings; but where, as in a jobbing shop, there are a few molds of wide variations, then it means more partly filled stoves for each temperature required, or a common mold temperature with variation in the composition of the cupola metal, such as one would make with ordinary dry-sand molds.

Another question arises if the shop is held up for an hour. How will this affect the temperature of the mold already out of the stove? The loss of heat from a dry-sand mold per hour, if the risers and runners are covered with a clay stopper, is very little—and no ill effect would follow if other conditions are normal.

It must be remembered, however, that there are limitations to the use of this process. The writer once travelled over 200 miles to see large turbines cast in perlite, but on arrival found they had never been cast thus. Any job that takes much time to close and difficulty in moving about without breaking core vents, cannot be attempted.

That excellent castings can be produced in perlite is a proven fact.

but all the claims put forward cannot be taken for granted. Often comparisons are made with other irons as to wear, strength, etc. Some of the cases I examined were not fair comparisons, and the composition and structure of the ordinary irons were such that nothing else could be expected. Therefore, it is best not to accept any statement unless the composition and structure of both castings are shown. This structure applies not only to perlit castings but also to the high test type.

Will the adoption of the perlit process so cut down the waste (leaving out all foundry faults) as to justify the extra cost when compared with a shop that has equal control on ordinary castings? This is problematical. I have known perlit castings to be made five times over before a satisfactory one was made, and others have given poor life.

This is not said in a critical spirit, but to show that the process is not quite so fool proof as is sometimes stated. It must be remembered that the possible variables are being increased to four, namely, mold temperature, casting temperature, composition, and thickness of section, as against only the last three in ordinary work. This means, also, that if one accepts the "germ" theory, one still is liable to alteration of structure by the type of metal charged.

Referring to the physical properties, it may be accepted at once that perlit iron seldom obtains the very high tests given by some of the modern high-test irons. This may be accounted for by the increase of grain size due to the slower cooling. That grain size, quite apart from graphite, has a decided influence on the physical properties has been shown by Becker and others. Becker took a white Swedish iron and cast bars in sand and in chills; the latter were much the stronger and still maintained their strength after annealing.

It may also be accepted that in properly made perlit there is much less variation between the outer and center of a large bar than in high-test iron, as shown by the following examples:

	TC	Si	Mn	S	P	Tensile* at		Brinell,		Size of Bar, in. diam.
						Edge	Center	Edge	Center	
Perlit (A. Smith)	3.20	0.66	0.78	0.13	0.46	18.0	16.9	217	207	5½
High Test (MacPherran)	2.55	2.23	0.70	0.084	0.54	23.4	17.0	237	241	4

* Tons per sq. in.

There is little doubt, however, that if MacPherran's iron had been lower in silicon, the difference between the edge and center would not have been so great. An iron of the following composition—TC 3.16 per cent, Si 0.82, Mn 0.51, S 0.12, P 0.21—gave over 17 tons on a tensile of 1.875 in. diam., and when turned down to 0.798 in. gave 16.10 tons, while the original 2.2 in. bar cast on gave 17,000 lbs. transverse tested at 18 in. centers.

One of the most disturbing features about both perlit and other high-test irons is the liability to fail under sudden shock. It would seem at times as if the structure was too close to allow that slight amount of spring necessary for the metal to recover itself.

I have investigated about a dozen cases during the last two years. Recently a casting failed at once under sudden stock. A test bar machined from the portion that failed showed a perfect pearlitic structure

all over the end section, with finely divided graphite. The composition was accepted by the customer as quite right. The tensile gave approximately 15 tons, while the repeated impact ran up to about 2000.

I am in perfect agreement with Mr. Young as to the uselessness of the usual tests for iron of this type, and in agreement that the use of the heavy and genuine impact test is necessary. The use of this test by the perlit people evidently is due to similar experiences to mine. This point was also confirmed by Dr. Werner, who stated that "inasmuch as irons having entirely perlitic structures had cracked, the tensile and transverse results were not sufficient and we must look for some other test."

It may seem that I have damned perlit with faint praise, but such is not the case. I only wish to point out that it is not the fool-proof thing it is sometimes made out to be. The main fact is that it is possible to use a lower silicon than with a cold mold and yet obtain a machinable casting practically free from the outside dendritic structure.

Report of A. F. A. Representative on Joint Committee on Investigation of the Effects of Phosphorus and Sulphur in Steel

TO MEMBERS OF AMERICAN FOUNDRYMEN'S ASSOCIATION :

Your representative on the Joint Committee on Investigation of Phosphorus and Sulphur in Steel, hereby reports no activity on the part of the said Joint Committee since the last convention of the American Foundrymen's Association, which relates to steel castings. Business conditions are responsible for the temporary suspension of work under the auspices of the Joint Committee.

Probabilities as to the time for resuming activities cannot now be confidently indicated. Industrial conditions will necessary govern that matter.

Respectfully submitted,

R. A. BULL,

*A. F. A. Representative on Joint Committee on
Investigation of Phosphorus and Sulphur in Steel.*

Some Foreign Methods of Testing Foundry Sands

BY H. RIES,* ITHACA, N. Y.

Abstract

The author presents a review of published material on European methods of sand tests, and discusses these methods as compared with those used in America. A general comparison indicates that the apparatus used abroad in many cases is not only different but apparently there has been less attempt on the part of foreign foundrymen to standardize methods. For fineness tests the British Cast Iron Research Association has adopted the elutriation method. The author compares this with the A. F. A. sieve method. Methods for testing permeability are described, and the effect of the density of the specimen on test results is discussed. Test methods for deformation, compression, tensile strength, durability, core quality, and refractoriness are reviewed.

1. Much attention has been given in recent years to the laboratory testing of foundry sands, as is shown by the many articles which have appeared in technical magazines devoted to the foundry industry. These contributions show, as might be expected, that the properties of sands regarded as necessary of evaluation are much the same in all countries. Thus we find that methods have been devised for studying or measuring the fineness, bond strength, permeability and refractoriness of the sands, although the apparatus used in all cases is not the same and the methods employed differ somewhat.

2. It is probably true that the American Foundrymen's Association has given greater attention to the important subject of sand testing than has any other organization, and it has presented the findings of its Committee on Molding Sand Research in great detail.¹ The British Cast Iron Research Association also has published a number of bulletins on foundry sands, one of which, No. 73 issued in 1930, deals with methods of testing.

* Department of Geology, Cornell University.

¹ *Testing and Grading of Foundry Sands—Standards and Tentative Standards*, American Foundrymen's Association, Chicago, 1931 edition.

3. A general comparison of American and foreign methods indicates not only that the apparatus used in many cases is different, but also that apparently there has been less attempt on the part of foreign foundrymen to standardize methods, so that it may be difficult or impossible for one operator to compare his results with another unless they both mutually agree to carry out their tests under exactly the same conditions. It is this attention to standardization of method in all its details which we believe enhances the value of the methods recommended by the A. F. A.

4. In this paper no attempt is made to review all the literature on the subject,² but simply to point out some interesting methods of testing that have been used abroad, and to venture a criticism of some of them.

FINENESS TESTS

Sieve Test.

5. In the United States we are accustomed to determining the texture of a sand by means of a sieve test, after first separating out, by settling, what we call "clay." By using calibrated sieves, accurate sorting can be obtained; and we are fortunate in having in this country a governmental bureau where this calibrating can be done.³

6. European foundrymen use wire cloth, silk gauze and perforated sieves. In no case where sieves are used has the writer noted any mention of a standard time for shaking, nor the use of any mechanical shaking apparatus.

7. One investigator, Dr. Aulich,⁴ makes the comment that sieving through wire sieves is wearisome because the meshes become clogged up, and he recommends the use of silk gauze because there is less binding. The possibility of the threads spreading easily is not considered.

Elutriation Test.

8. In the elutriation method the sand is subjected to a rising current of water, the size of the particles removed depending on

² An interesting historical resumé of the development of certain testing methods will be found in *Bulletin 73*, 1930, British Cast Iron Research Association, Birmingham, England.

³ For description of method used, see U. S. Bureau of Standards, *Letter Circular L. C. 73*, July 26, 1922.

⁴ *Die Giesserei*, Oct. 9, 1931.

the velocity of the current. One claim made for the elutriation method is that it permits a separation of clay and fine silt, both of which are included under "clay" in the A. F. A. fineness test. Since fine silt is regarded by some as having little or no bonding strength, the separation of the two might be desirable, and its omission may be a defect in our fineness test.

9. In Europe, including England, the use of the elutriation method is widespread, sieves being used less often, particularly in England, where the claim is made by some that they are altogether too inaccurate. There are several types of elutriators in use abroad, and the grain sizes separated by them are not the same

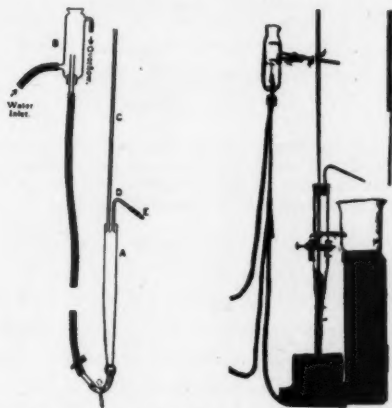


FIG. 1—BOSWELL ELUTRIATOR. (BRITISH CAST IRON RESEARCH ASSOCIATION, BULLETIN 73, 1930.)

in all cases. Indeed, the results may vary with the time of operation. None of the discussions of elutriation methods published appear to take into account the effect of the temperature of the water on the results obtained.

10. Space does not permit a description of all the types of elutriators used. Some, like the Treuheit apparatus,⁵ or that of Nipper,⁶ consist of a series of receptacles connected in order of increasing diameter, so that as the water passes from the narrower to the wider tubes or containers, the current slows down. The coarser grains settle in the narrower receptacles and the finer in the wider ones, the clay particles being carried off.

⁵ *Stahl und Eisen*, Nov. 1, 1923; also *Die Giesserei*, no. 21, 1930.

⁶ *Die Giesserei*, no. 21, 1930.

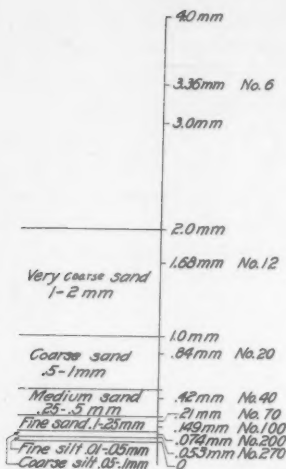


FIG. 2—SCALE SHOWING OPENINGS OF BUREAU OF STANDARDS SIEVE SERIES, AND SIZE SEPARATED BY BRITISH CAST IRON RESEARCH ASSOCIATION. LEFT-HAND COLUMN GIVES BRITISH GRADES. RIGHT-HAND COLUMN GIVES SCREEN SIZES OF A. F. A. FINENESS TEST.

11. *Boswell Elutriator.* The method approved by the British Cast Iron Research Association is that which uses the Boswell elutriator, shown in Fig. 1. With this apparatus 10 grams of sand is used, dried and put in a 600-c.c. evaporating dish covered with 250 c.c. of distilled water to which 10 drops of concentrated ammonia is added. This is boiled for ten minutes.⁷ If the sand contains grains larger than 1 mm., it is first put through a perforated sieve of that mesh. The remainder of the sample is transferred to the elutriator (the velocity of whose current is properly adjusted) and run until the water passing off is clear. This removes the clay.

12. The contents then are run into an evaporating dish, allowed to stand for 10 minutes, the clear water decanted off and the sample dried and weighed. The sample then is replaced in the elutriator and the current speeded up to carry off the fine silt grains. The residue is treated as before and weighed again. The coarse silt and fine sand are handled similarly.

13. Any remaining residue is placed on a 0.5-mm. perforated sieve so as to remove medium sand. Further treatment of ma-

⁷ Disintegration of the sand by boiling appears to be the prevailing method abroad. The author has seen no mention of rotary shakers or stirrers. Dr. Skerl of the British Cast Iron Research Association criticizes the stirrer, claiming that it rubs the static bond off the sand grains.

terial remaining on the 0.5-mm. sieve, with 1-, 2- and 4-mm. sieves, removes the coarse sand, very coarse sand, and gravel. It will be noted that perforated or round-hole sieves are used, which do not give the same results as wire-cloth sieves of the same size opening.

14. Fig. 2 gives a scale on which the sizes separated by the British process and the A. F. A. method are compared.

15. We are told by Dr. Skerl that the entire process requires 8 hours, which is not much saving over the time needed for the A. F. A. method. Instead of using one elutriator, several can be set up side by side, each one adjusted so as to wash off a certain size grain.

16. Granted that we have calibrated sieves, the author still fails to see that elutriation possesses any advantage over the A. F. A. sieve test, except for separating true clay and fine silt.

Washing Sample.

17. Both the English and Germans use smaller sand samples than we do, and both advocate preparation of the sample by boiling. Dr. Skerl of the British Cast Iron Research Association laboratory informs us that the reason for using ammonia is because other alkalis have an effect on the iron oxide, which is a common bonding material in British sands.

18. That the use of ammonia is not applicable to our sands would seem to be indicated by experiments carried out by W. M. Saunders some years ago. Mr. Saunders informs the writer that experiments made on about fifty sands from New York, New Jersey and Ohio showed that, on an average, 2 per cent more clay substance was obtained with sodium hydroxide of 1 per cent strength than with ammonia.

PERMEABILITY

19. In view of the fact that permeability is such an important property, it is unfortunate that no universal method is in use for making a permeability test. In the United States, as is well known, the test has been standardized in all its details, and in England the British Cast Iron Research Association has recommended using the L. H. Cole apparatus,⁸ while on the Continent no uniform method appears to have been adopted.

⁸ Canadian Dept. of Mines, Mines Branch, *Bulletin* 21, 1917; also *Permeability Testing of Molding Sands*, TRANSACTIONS A. F. A. (1925), vol. 32, pt. 2, p. 165.

Cole Permeability Apparatus.

20. It may be of interest and value to make certain comments on the Cole permeability apparatus, as it differs so markedly from the A. F. A. standard type. Briefly, the former consists of a sand cylinder 8 in. long and 2.8 in. (7.14 cm.) in diameter. This rests on a receptacle (Fig. 3) through which illuminating gas is forced under a known pressure. A pilot light is burned at the top of the cylinder, and the gas is ignited by this as soon as it reaches the top. The time is noted from the instant the gas is turned on until it lights at the top, and this is taken as a measure of the permeability.

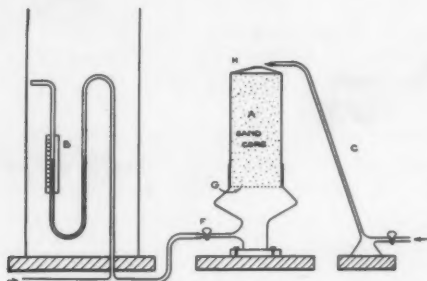


FIG. 3—COLE PERMEABILITY APPARATUS. (BRITISH CAST IRON RESEARCH ASSOCIATION, BULLETIN 73, 1930.)

21. It is stated that for research work a gas pressure of 7 cm. is used, but that there is a definite relation between gas pressure and time taken for gas to pass through the core. Thus:

Time in seconds \times pressure in centimeters = a constant. If pressure is 5 cm., and time 35 seconds, and we desire to calculate time for 7 cm. pressure, then

$$35 \text{ sec.} \times 5 \text{ cm.} = 175$$

$$\frac{175}{7} = 25 \text{ sec., time required for higher pressure.}$$

22. The permeability test is repeated several times at different ramming densities for each moisture per cent, the time being plotted against ramming density.

23. *Effect of Density of Specimen.* It is claimed that there is a straight-line relationship between apparent density and weight of core. One defect in this method is that there is no specified

method for filling the cylinder with sand. It may be rammed by hand, jolting or any other method desired, which prevents standards of comparison. It is true that the apparent density of the sand is determined and is obtained by dividing the weight of the sand by its volume, but this will vary.

24. The criticism which some of our English friends make of the A. F. A. permeability apparatus is that it is unsatisfactory from both a scientific and a practical standpoint. They also criticize our uniform method of ramming because they claim that the density developed is not the same as it is in all kinds of molds. The A. F. A. method, however, does involve testing under uniform conditions, which permits better comparison by different operators. If desired, one can vary the number of rams given a sand.

25. It may be interesting, therefore, to compare the apparent density that we get with our standard rammer, with that quoted for some English experiments. Buchanan, in a recent paper⁹ on sand testing, shows apparent densities ranging from 1.4 to 1.9. These, of course, may vary with the amount of ramming and per cent of moisture.

26. In order to determine what results are obtained with the A. F. A. rammer, the writer made some tests with a coarse Albany sand. The results were as follows:

No. Rams.	Apparent Density.	
1	1.61	} Moisture 4.5
2	1.67	
3	1.74	

27. For some other sands, with 3 rams, we obtained figures ranging from 1.7 to 1.94. Increased water always gave increased density. It is claimed that with uniform water content and ramming, the apparent density will vary with the texture of the sand.

Type of Gas and Permeability.

28. F. Roll has called attention to the fact¹⁰ that permeability varies with the nature of the gas passing through the sand. He states that CO₂ passes through sand more rapidly than air, this being connected with the diffusion coefficient. Roll does not give any figures in his paper to show why he arrived at this conclusion.

⁹ *Foundry Trade Journal*, Feb. 11, 1932.

¹⁰ *Die Giesserei*, Apr. 26, 1929, p. 393.

DEFORMATION TEST

29. It is a well-recognized fact that when a sand specimen is tested in compression it may deform slightly before rupturing, and that the amount of deformation may be measured. Unfortunately, perhaps, little attention has been given to this property, which may possibly have a bearing on the flowability of the sand.

30. Two German investigators, Aulich and Lewerenz,¹¹ have determined the deformation points and compressive strength of a series of sands. The pressure at which the deformation begins is expressed in percentage terms of the load required to break the

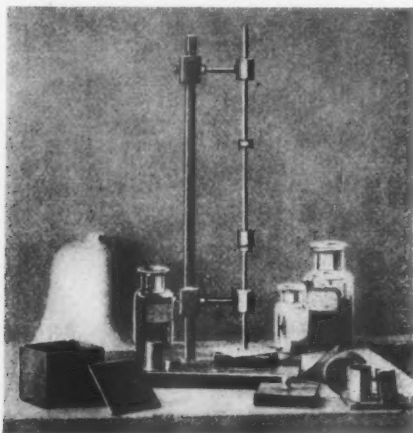


FIG. 4—DEFORMATION APPARATUS USED BY NIPPER AND PIWOWARSKY. (DIE GIESSEREI, No. 48, 1929.)

test specimen under compression, and was found to vary from 56.9 to 93.7 per cent.

31. A sand which has a deformation point of 95.4 per cent is regarded as good, while one having a deformation point of 89.5 per cent is considered less desirable. If the deformation point is too low, the authors state that the mold is liable to yield to the pressure of the molten metal.

32. Sands with a strong clay content may show the highest compression strength, but their deformation point usually is lower. Table 1 brings out some of these points.

¹¹ *Die Gießerei*, vol. 17, p. 875, 1930.

Table 1
RELATION OF CLAY CONTENT TO DEFORMATION POINT, IN PER CENT
OF COMPRESSIVE STRENGTH.

Sand Type	Sand %	Clay, %	Grain Size					H ₂ O, %	Permea- bility, cu. cm. per min.	Shear Str., grms. per sq. cm.	Com- pression, grms. per sq. cm.	Deforma- tion Pt., in ret. terms grms. per sq. cm.	Deform. in ret. terms of Com- pressive St ^g th., %
			Over 0.3 mm.	0.2- 0.3 mm.	0.09 -0.2 mm.	0.05 mm.	Under 0.05 mm.						
1. Coarse grained, lean.....	92.8	7.2	43.3	26.4	17.8	1.1	4.2	5.2	63	140	670	525	78.4
2. Coarse grained, medium fat.....	88.0	12.0	22.7	24.9	28.1	3.0	8.3	6.2	40	176	715	670	93.7
3. Coarse grained, fat.....	79.6	20.4	3.4	34.9	22.4	2.3	16.6	9.9	20	317	1180	830	70.3
1. Medium grained, lean.....	93.2	6.8	0.3	2.6	69.5	14.5	6.3	4.5	34	84	320	260	81.3
2. Medium grained, medium fat.....	88.0	12.0	5.7	13.7	52.6	7.8	8.2	5.0	40	150	545	520	95.4
3. Medium grained, fat.....	79.6	20.4	6.0	12.8	50.5	1.6	8.7	10.3	43	310	1090	620	56.9
1. Fine grained, lean.....	92.7	7.3	0.6	0.7	17.5	10.1	63.8	6.1	8	77	305	245	86.9
2. Fine grained, medium fat.....	87.4	12.6	10.3	3.3	19.2	13.6	41.0	7.0	9	119	570	510	86.5
3. Fine grained, fat.....	80.0	20.0	3.4	1.3	3.8	2.8	68.2	8.0	5	208	715	595	82.9

33. Dr. Aulich considers the compression test to be the best one to make for strength, because it permits measurement of deformation at the same time.

Nipper and Piwowsky Deformation Test.

34. Some writers, like Nipper and Piwowsky, suggest a separate deformation test, which is different from the one just described. This consists in forming a cylinder of sand 50 mm. (2 in.) high and 50 mm. in diameter. This core is made in a split tube on a jolting machine. It is then removed from the tube and placed on the base plate of the testing machine (Fig. 4).

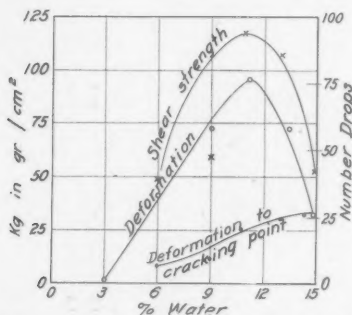


FIG. 5—GRAPH SHOWING EFFECT OF MOISTURE CONTENT ON SHEAR STRENGTH (A), DEFORMATION (B), AND CRACKING OF SAND (C). (DIE GIESSEREI, No. 48, 1929.)

35. The essential parts of the machine are a plate fastened to the lower end of a rod which slides vertically in two guides. A weight of 152 gm. slides freely on this rod between two fixed stops, which limit the drop height of the weight. The plate at the lower end of the rod rests on the test piece, and the weight is dropped from a height of 15 cm. (6 in.), striking a blow against lower stop.

36. These blows are repeated, and the number noted which are required to develop cracks in the test piece, and also the number required to flatten the core 2 cm. (4/5 in.) The work done by the drop weight can be translated into foot pounds or other units of force.

37. The authors themselves give no explanation of the value of the test. However, they give one graph (Fig. 5), which is of

interest as showing the relation between shear strength, complete deformation, and cracking in the same clay with increasing water content. It will be noted that the curves for the first two show a peak and are practically parallel, but that for the last, the curve rises steadily as the water content increases.

TENSILE STRENGTH

38. Little attention appears to be given to the tensile strength test in the foreign literature, but H. Nipper and E. Piwowarsky¹² recommend a different type of core holder from that suggested by the late A. A. Grubb. It consists of a brass receptacle which in section is hour-glass shaped. It is filled by jolting and is not as easy to handle as the type recommended by the A. F. A.

DURABILITY

39. No standard test has been recommended as yet for determining the durability of a sand, although several have been suggested by Dietert,¹³ Nevin,¹⁴ and Blakey.¹⁵

40. One rather interesting test suggested by Dr. Roll¹⁶ resembles the settling test proposed by the late Eugene Smith. It is carried out on used sands, and the percentages of clay substance represented by the upper layer in the test tube decreases as bond is destroyed by heating. In fact, Dr. Roll states that the results obtained with this test show a curiously close relation to those obtained with the dye adsorption and strength test.

CORE TESTING

41. Little consideration appears to have been given to special methods for testing cores in foreign laboratories, but one test described by Riebold and Prinz is rather interesting. It deals with the evolution of gas.

Evolution of Gas.

42. For making this test,¹⁷ the core mixture is rammed into a $\frac{3}{4}$ -in. piece of gas pipe, closed at one end and threaded at the

¹² *Die Giesserei*, vol. 16, Mar. 8, 1929.

¹³ *TRANSACTIONS A. F. A.* (1925), vol. 33, p. 735.

¹⁴ *IBID* (1925) vol. 33, p. 785.

¹⁵ *IBID* (1928), vol. 36, p. 3.

¹⁶ *Die Giesserei*, Apr. 26, 1929, p. 597.

¹⁷ A. Riebold and Th. Prinz, *Die Giesserei*, Sept. 6, 1929, p. 820.

other. After thorough drying, this tube is set in the wall of a mold (Fig. 6) so that the closed end projects into the mold cavity. The threaded end of the pipe connects with a tube leading to the displacement bottle, which is filled with water. Another tube also connects with the pressure gage.

43. Molten metal at a temperature of 1300 degs. Cent. (2372 degs. Fahr.) then is poured into the mold, and the gases driven out of the core mixture by this heat are forced into the displacement bottle, the water so forced out being caught in a measuring jar—thus determining the volume of gas forced out. Pressure readings are taken every 10 seconds for the first half hour, and thereafter at 30-second intervals.

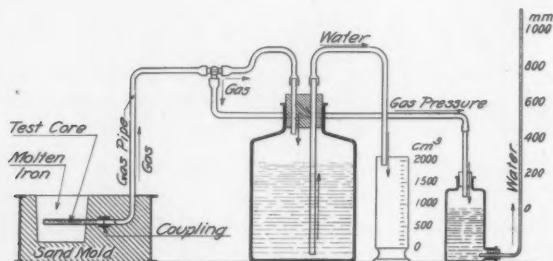


FIG. 6—APPARATUS FOR TESTING GAS EVOLUTION OF CORES, AFTER RIEBOLD AND PRINZ. (DIE GIESSEREI, No. 36, 1929.)

Permeability.

44. For the permeability test the authors Riebold and Prinz recommend a core $3 \times 1 \times 1$ in., properly dried. This is coated with paraffin and, after the latter has been cleaned off the ends, the core is placed in the funnel-shaped receptacle shown in the apparatus (Fig. 7), the joint being sealed with paraffin. The stopcock at bottom of the 5-litre water bottle is opened and the water drawn off. The time required to empty the bottle is measured. A previous test is made without the core in place, and the time measured.

45. The latter time divided by the first, times 100, gives the permeability. The object of the pressure gage shown in the figure is to determine irregularities of pressure which might indicate a leak.

COMPRESSION TEST

46. While the compression test is described or referred to by a number of writers, there is nothing particularly novel in the method of making it.

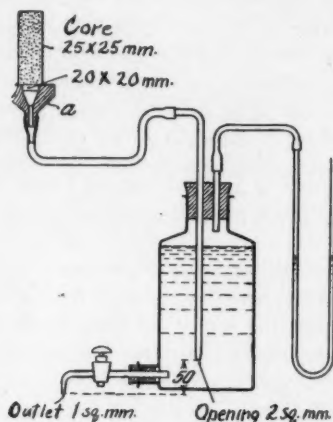


FIG. T.—APPARATUS FOR TESTING PERMEABILITY OF CORES, AFTER RIEBOLD AND PRINZ. (DIE GIESSEREI, No. 36, 1929.)

47. In the handbook of the British Cast Iron Research Association (*Bulletin 73*, 1930) the core is said to be formed by ramming, but just how this is to be carried out is not specified. Cylindrical cores of 1 in. diameter and either 1 or 2.25 height are recommended. It is stated that the former is useful for research work carried out in metric units, and the latter for control purposes in the foundry.

48. It is obvious, however, that the same sand tested in these two shapes would not give comparable results. A point is made of weighing the core and determining the volume weight from which the apparent density is figured. It is advised that the cores can be tested with different degrees of ramming.

49. W. Y. Buchanan¹⁸ claims that the small cores are difficult to produce and may show considerable difference in strength even though variation in density may be small. He also found that hand-rammed cores broke easily on being removed from the core box, and that pressing gave better results. Here again the personal

¹⁸ *Foundry Trade Journal*, Feb. 11, 1932.

equation comes in, as it is suggested that this may be done by hand.

50. In discussing the ramming of cores, Dr. Roll¹⁹ has some interesting comments to make, pointing out that densification proceeds differently whether ramming or jolting is used. Thus, with ramming, the sand becomes denser in the upper part of the core and toward the sides (Fig. 8), whereas in jolting, densification is greater toward the bottom of the core. Furthermore, in comparing a coarse or fine textured sand, with different amounts of clay, the fine-grained, high-clay sand densified more at top with ramming or pressing, whereas in the coarse one with lower clay content, the pressure is transmitted better toward the bottom.

REFRACTORINESS

51. This property has received as much attention by foreign writers as any other. Various methods are used. A common one appears to be to heat the sand to different temperatures and note the temperature at which sintering begins. In other cases the sand is formed into cones similar to Seger cones and several of the latter placed with the sand in the furnace, to determine the fusion point.

52. The British Cast Iron Research Association suggests determining the fusing point of the clay bond separately. This is a reasonable suggestion, for, as pointed out by D. W. Trainer, Jr.,²⁰

¹⁹ *Die Giesserei*, Apr. 26, 1929, p. 398.

²⁰ *TRANSACTIONS A. F. A.* (1926), vol. 34, p. 327.

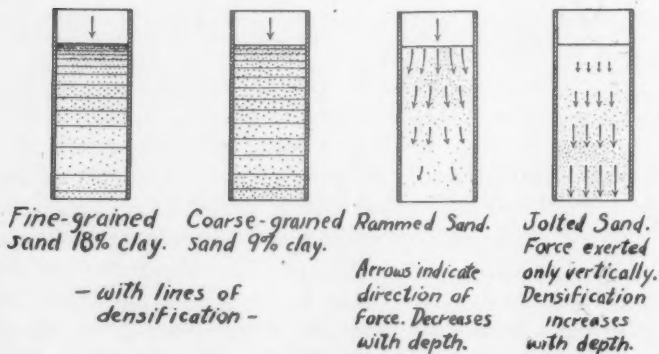


FIG. 8—TYPE OF DENSIFICATION PRODUCED IN SANDS BY RAMMING AND JOLTING. (DIE GIESSEREI.)

the refractoriness of the bond exerts an important influence on the fusibility of the sand as a whole. Some writers have suggested that the behavior of the sand toward both heat and chemical action should be determined, and for this purpose the sand is formed into a crucible into which molten metal of known temperature is poured.

CONCLUSIONS

53. In considering the entire subject of sand testing as carried out in foreign countries, one becomes impressed with the variety of apparatus that has been devised for testing the same property. There might be no serious objection to this if the results obtained in all cases were comparable, but this is not the case. Where standard apparatus is recommended, as in England, a standardized method of preparing the sample is not insisted on in all cases, and this seems a serious omission. Much is made of the apparent density of the sand by English writers, and this is also referred to by some German investigators.

54. It might seem desirable to have international standards, at least covering those countries drawing upon the same sources of supply, as this would work for better understanding between producer and consumer. It may be a debatable point whether the Europeans should have the same standard methods as the Americans, and yet for discussing questions of foundry sand technique it would be very desirable. We have no knowledge of the A. F. A. standards having been officially adopted in Europe, although a number of sets of American apparatus have been shipped abroad.

The Influence of Design on Brass and Bronze Castings

By LEWIS H. FAWCETT,* WASHINGTON.

Abstract

The author stresses the attention which should be given the designing of castings in relation to foundry production. Selection of the alloy to be used is important, as is the determination of molding position to prevent shrinkage. Composition of some bronzes and brasses used by the Navy Department are given, together with the required physical properties. The fundamentals of design are discussed and many examples of poor design are shown with improvements which can be made to overcome the defective design. Evenness of metal section is stressed as of the greatest importance in securing sound castings.

1. Engineers responsible for the design of castings required in engineering projects give careful consideration to the composition of the alloy selected and its mechanical properties, with sufficient allowance for the proper factor of safety. However, in many instances this same consideration has not been given to the foundry problems involved in the production of the casting, and their influence on the ultimate value of the casting.

2. Unfortunately, reliable data on this subject are not always readily obtainable in concise form for the use of designers. It is the purpose of this paper to outline briefly some of these problems and to present some simple illustrations of good and poor design for brass and bronze castings.

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SELECTION OF ALLOY

3. In the selection of an alloy, consideration should be given not only to meeting the requirements of the design but also to aid production and minimize foundry difficulties. When possible, an alloy should be selected permitting the use of a minimum amount of gates and shrink heads to obtain the maximum yield from the metal melted.

4. A brass with high shrinkage may have a low intrinsic value and yet have a high manufacturing cost, due to the excess metal needed for heads and gates and the additional molding necessary when using such an alloy. Such a brass would have a

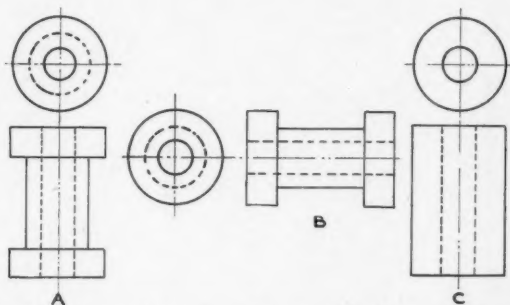


FIG. 1—SIMPLE BRONZE CYLINDRICAL BUSHING. A: PROBABLE CASTING POSITION, WITH SHRINK ON TOP OF FLANGE. SOME SHRINKAGE IS TO BE EXPECTED IN FLANGE. B: IF LARGE AMOUNT OF METAL IS REMOVED IN MACHINING, THIS WOULD BE PREFERRED POURING POSITION, AS COMPARED WITH A. IN POSITION B, HEADS WOULD BE LOCATED ON TOP OF BOTH FLANGES. C: PREFERRED DESIGN FOR BUSHING TO BE POURED OF A HIGH-SHRINKAGE BRASS OR MANGANESE BRONZE.

tendency to form scurf on its surface; but, in general, it would have a fairly uniform grain size so that the interior metal would about equal the surface metal in soundness.

5. A bronze would give a smooth, even, close-grained surface of uniform pleasing color and be produced with less molding labor and less excess metal in heads and gates. The bronze casting, however, probably would have a relatively coarse-grained interior structure as compared with the structure of the casting's exterior surface.

6. Table 1 gives the composition and mechanical properties

Table 1
COMPOSITION AND MECHANICAL PROPERTIES OF BRONZE
Chemical Requirements

Navy Department Specifications.	Composition.	Cu, %	Sn, %	Zn, %	Pb, %	Fe, max. %	Ni, max. %	P, %	S, max. %	Sb, max. %	Other Elements, max. %
Phosphor Bronze 46-B-5f	Desired.	88.0	8.0	4.0	0	0	....	0	0	0	0
	Permissible.	83.0-89.0	7.5-11.0	1.5-4.5	0-1.0	0.25	0.75	0.5	0.05	0.25	0.35
Gun Metal 46-M-6e	Desired.	88.0	8.0	4.0	0	0	....	0	0	0	0
	Permissible.	86.0-89.0	7.5-11.0	1.5-4.5	0-0.30	0.10	0.75	0.05	0.05	0.25	0.15

Mechanical Requirements

Navy Department Specifications.	Tensile Strength in Lbs. per Sq. In., minimum	Elongation in 2 in., minimum
Phosphor Bronze 46-B-5f	35,000	18.0
Gun Metal 46-M-6e	40,000	20.0

Table 2
COMPOSITION AND MECHANICAL PROPERTIES OF BRASS
Chemical Requirements

Navy Department Specifications.	Composition.	Cu, %	Zn, %	Pb, max. %	Al, max. %	Mn, max. %	Fe, max. %	Sn, max. %	Other Elements, max. %
Naval Brass 46-B-10d	Desired.	62.5	36.3	0	0.2	....	0	1.0	....
	Permissible.	60.0-65.0	†	0-1.0	0.5	....	0.5	0.5-1.5	....
Manganese Bronze 46-B-3c*		55.0-60.0	38.0-42.0	0.30	1.50	3.50	0.40-2.00	1.50	0.20

Mechanical Requirements

Navy Department Specifications.	Tensile Strength in Lbs. Sq. In., minimum.	Elongation in 2 in., minimum.
Naval Brass 46-B-10d	30,000	15.0
Manganese Bronze 46-B-3c*	65,000	20.0

* A high-test brass.
† Remainder.

of two well-known bronzes, and similar information regarding brass is shown in Table 2.

Bronze Cylindrical Bushing

7. The cylindrical bushing shown in Fig. 1, if made of bronze, in all probability would be cast in a vertical position, as shown in *A* of Fig. 1. The shrink head would be placed on the top flange.

8. This, of course, does not give ideal conditions during solidification, as the metal must feed the bottom flange through the relatively thin cylinder. The thin section would solidify before the bottom flange and thus cut off the supply of liquid metal during the latter part of the freezing period of the bottom flange. Nevertheless, this procedure would result in a satisfactory casting, and if too much metal was not removed in machining, the casting would withstand a high hydrostatic pressure.

9. If, on the other hand, a large amount of the fine-grained surface metal was removed by machining, it probably would leak (under water pressure) at the junction of the side wall and bottom flange, due to the relatively coarse-grained interior metal allowing the water to seep through. By surface metal is meant the metal in contact with the sand; the interior and exterior of the cylinder would be alike in this respect.

10. To insure more perfect feeding the cylinder may be cast horizontally, as shown in *B* of Fig. 1. In this case a head would be located on top of each flange. The thin body of the casting would solidify before the end flanges, but liquid metal in the head would be available for feeding the flanges during the whole time of their solidification.

11. If the casting was as simple as the one shown in the sketch, it could be cast in this manner. However, many castings which involve these principles have a much more complicated contour, and it is more practical to pour them in a vertical position.

Brass Cylindrical Bushing

12. If the bushing was to be made of brass or manganese bronze (a high-shrinkage brass), it would be more satisfactory to pour a hollow cylinder as shown in *C* of Fig. 1. This method would insure perfect feeding, as the casting is of uniform thick-

ness throughout. Furthermore, it would allow the dross to rise and collect in the shrink head above without any tendency to be trapped in corners.

13. The cylinder then could be machined to the contour of the bushing. The machining would remove any scurf that might be present on the surface and would not affect the ability of the casting to withstand hydrostatic pressure because the metal does not have a tendency to form a relatively coarse-grain interior, as compared with bronze.

14. Considering all the factors involved, it probably would be more economical to make this bushing of bronze rather than of brass—especially so where the casting is required to withstand water pressure.

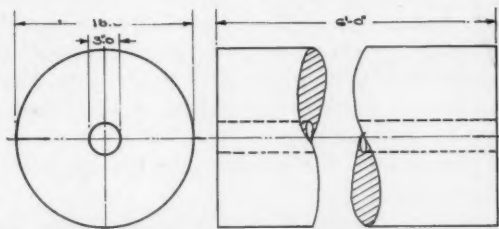


FIG. 2—EXAGGERATED EXAMPLE OF CASTING THAT WOULD BE MADE MORE SATISFACTORILY OF BRASS THAN OF BRONZE.

Considerations in Selecting Proper Alloy

15. Fig. 2 shows an exaggerated example of a casting that would be made more satisfactorily of brass than of bronze. The casting is 18 inches in diameter, 6 feet long and has a 3-in. diameter hole which is to be cored out with sand. The result is a large volume of metal surrounding a small area of sand. The metal is, in turn, surrounded by the refractory sand of the mold which, of course, retards its rate of cooling.

16. If this job was made of bronze there would be a tendency for "tin sweat" to penetrate the sand core, making the removal of the core extremely difficult and resulting in a hard, irregular surface within the hole. Tin sweat is hard and difficult to machine. It frequently has a tin content of about 20 per cent, but may run higher or lower than this figure. Other things being

equal, the higher the tin content of the bronze, the greater the tendency to form tin sweat.

DESIGN

Uniformity of Cross-Sectional Area

17. The ideal casting should be designed to have the same cross-sectional area throughout at the time of pouring. Of course, such uniform thickness is not to be expected in most castings but should be provided wherever practical. At times the allowance for machine finish may cause non-uniformity, although the final machined article may be uniform.

18. When uniform cross-sections are not possible, an abrupt change from one cross-section to another should be avoided by the liberal use of fillets, which will eliminate right-angle bends and sharp corners and greatly aid in the production of sound castings. Wherever sudden changes in section occur, the lighter section may have completed liquid shrinkage and solid contraction started, whereas the heavier section may still be in the liquid shrinking status, resulting in a rupture or strain at the union of the two sections if proper fillets or brackets are not employed at their intersection.

19. When it is necessary to attach lugs, bosses, brackets or other projections to the body of a casting, uniformity of metal should be maintained as far as practical, even though it requires the coring out of such projections. An intended solid boss, attached to the casting, may be weaker than a lighter boss that has been cored out but is entirely sound.

20. Uniform cross-section, the proper use of fillets, rounded corners, coring of heavy lugs and bosses, the avoidance of sharp corners and right angle bends are details of design that greatly aid in the manufacture of sound castings.

Cooperation of Designer and Foundryman Recommended

21. Furthermore, in the interest of sound castings it is essential that the designer visualize the various molding methods applicable to his design so that he may make modifications which will permit the proper feeding of all the principal parts of the job, or which will result in lightening the casting.

22. If the designer does not have sufficient knowledge of

molding practice for such a survey, it is strongly recommended that he consult a foundryman and obtain his suggestions in the interest of soundness, prior to the completion of the design. Conferences between those producing castings and the designer often have resulted in the production of some very difficult and intricate castings which otherwise might have proved a failure.

Importance of Proper Draft

23. Frequently, pattern makers are reluctant to put ample draft on patterns when the drawing shows straight sides and the pattern maker does not know whether draft would affect the finished product. When possible, the drawing should specify a taper or authorized draft.

24. Sufficient draft will aid in the removal of the pattern from the sand without undue rapping, with the result that the sand will remain firm and thus obviate inaccuracy in the dimensions of the casting. Proper draft results in the casting being a truer replica of the pattern, decreases losses due to mold troubles, and is one of the largest factors in increasing production.

EXAMPLES OF GOOD AND BAD DESIGN

25. Accompanying sketches and photographs give some examples of good and bad design of brass and bronze castings.

26. Fig. 3 shows the intersection of two members of equal thickness. The sharp corner shown in poor design (at the left of the drawing) should be eliminated by a gradual tapering from one section to the other, as shown in the good design to the right. At times the tapering may take the form of only a small fillet to avoid the right-angle bend, but in any event it will greatly aid in the elimination of stress concentration at such an intersection and is most essential at the junction of thick and thin sections.

27. In Fig. 4 a too-liberal use of fillets at the intersection of ribs has caused an increase in the width of the intersection and thus has caused non-uniformity at this point. This may be overcome, as shown on the right of the drawing, by coring out the center of the intersection down to the body of the casting.

28. Fig. 5 gives an example of staggered ribs designed to avoid intersections. The fillets also are slightly reduced.

29. The diagonal bracket shown as poor design in Fig. 6 is a common error. The bracket has been made larger than the ad-

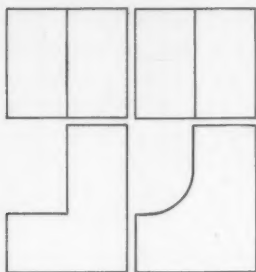


FIG. 3—POOR (LEFT) AND GOOD (RIGHT) DESIGN OF INTERSECTIONS.

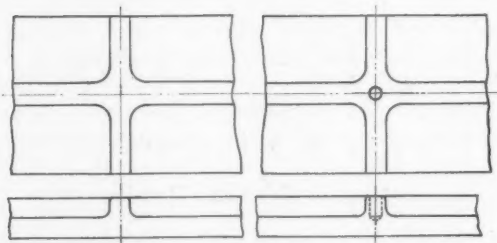


FIG. 4—Left: RIB INTERSECTION OF POOR DESIGN. Right: BETTER DESIGN OF RIB INTERSECTION.

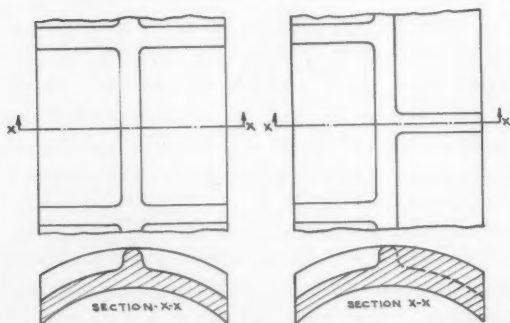


FIG. 5—EXAMPLE OF STAGGERED RIBS DESIGNED TO AVOID INTERSECTIONS AT RIGHT. AT LEFT, ORIGINAL DESIGN WHICH GIVES UNDULY HEAVY METAL THICKNESS AT INTERSECTIONS OF RIBS.

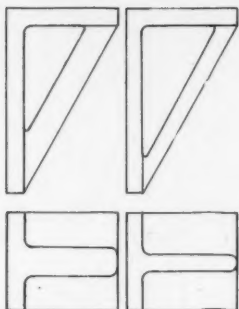


FIG. 6—*Left*: BRACKET SUPPORT IS TOO HEAVY, CAUSING WEAKNESS DUE TO UNEVEN METAL SECTION. *Right*: THIS FAULT CORRECTED.

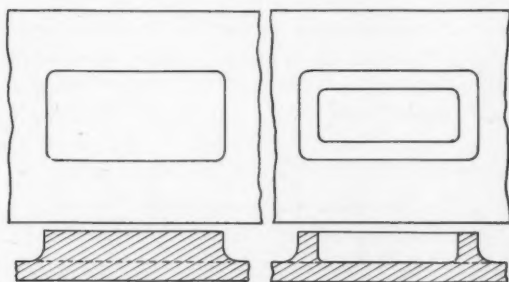


FIG. 7—POOR (LEFT) AND GOOD (RIGHT) DESIGN FOR BOLTING PLATES OR PADS.

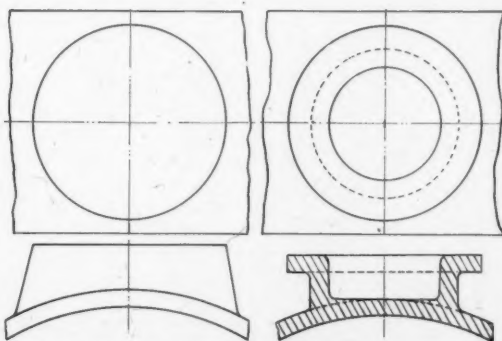


FIG. 8—POOR (LEFT) AND GOOD DESIGN (RIGHT) OF PROJECTION ON CYLINDER.

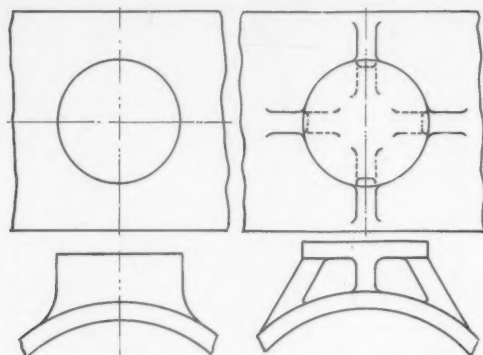


FIG. 9—POOR (LEFT) AND GOOD DESIGN (RIGHT) OF BOLTING PADS ON CYLINDER.

joining metal to add strength to the casting, but it has quite the opposite effect. The two sides of the triangle will solidify before the hypotenuse and thus enter the solid contracting stage with a tendency to shrink away from the thicker member before the latter is completely solid. The bracket should be of equal thickness whenever possible, as shown at the right of the drawing.

30. Fig. 7 shows poor and good design for bolting plates or pads. Such projections should be cored out so that the cross-section of these members will be as uniform as possible with the body and thus avoid unnecessary increases in local thickness.

31. Fig. 8 gives another illustration of coring out of a projection to maintain, as far as possible, equal thickness of metal. The lug is changed to a flange in this case.

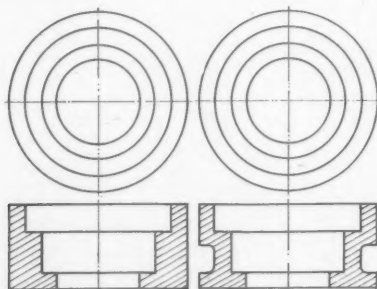


FIG. 10—EXAMPLE WHERE GREATER STRENGTH IS OBTAINED BY LIGHTENING CASTING, AS SHOWN IN DESIGN AT RIGHT. ORIGINAL DESIGN AT LEFT.

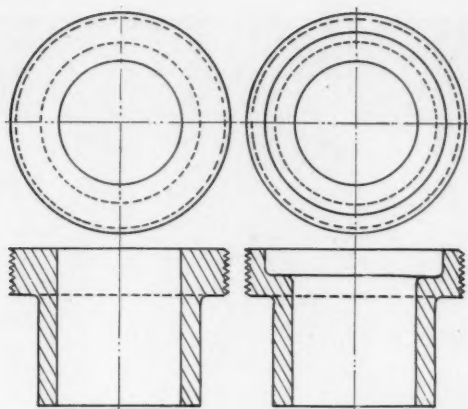


FIG. 11—POOR (LEFT) AND GOOD DESIGN (RIGHT) OF THREADED COLLAR.

32. Fig. 9 shows a great reduction in metal thickness by modification of design without decreasing the bolting or bearing surface of the projection.

33. In Fig. 10 uniform cross-section is obtained by coring out a section around the lower circumference of the casting. This also results in lightening the casting.

34. Fig. 11 gives an illustration of a threaded collar on the end of a casting causing non-uniformity of metal. Uniform thickness of metal is obtained as shown on the right of the drawing.

35. Fig. 12 shows a rectangular key-way with sharp corners. This design may be improved by substituting

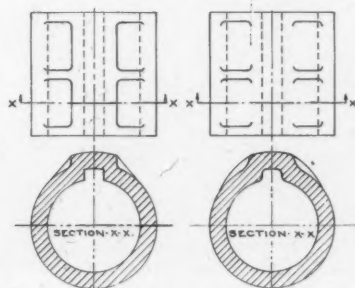


FIG. 12—POOR (LEFT) AND GOOD DESIGN (RIGHT) OF KEY-WAY.

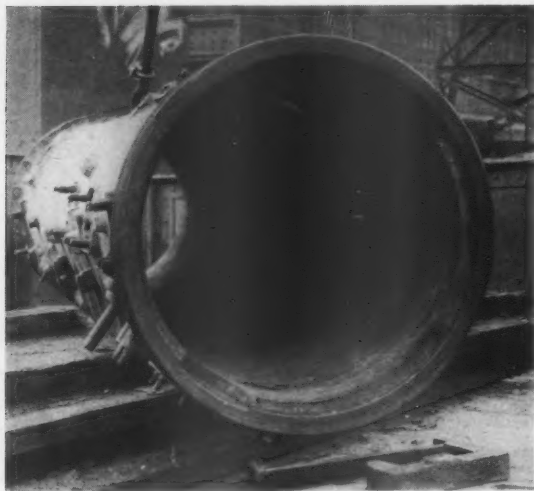


FIG. 13—LARGE BRONZE CYLINDER OF GOOD DESIGN, SECURED THROUGH CO-OPERATION BETWEEN DESIGNER AND FOUNDRYMAN.

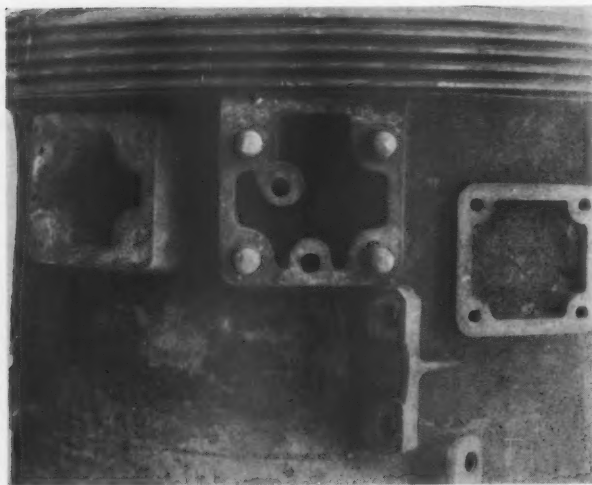


FIG. 14—DESIGN SHOWING CARE TAKEN TO AVOID INEQUALITIES IN SECTION OF CASTING.



FIG. 15—LARGE RECTANGULAR FLANGE CORED OUT UNDERNEATH TO AVOID INEQUALITIES OF SECTION. NOTE ALSO THE EASY ROLLING RIBS AND ROUNDED RIB OVER KEY-WAY.

a rounded ridge over the key-way and easy-rolling ribs, as given to the right of the drawing. A very slight fillet also may be inserted in each sharp corner of the key-way.

36. The large bronze casting illustrated by the photograph shown as Fig. 13 is the result of cooperation between designer and foundryman, and represents practical example of the principles previously mentioned. The casting has a large flange on each end and many projections on its body. Attention is directed especially to the coring out of the interior of the large flange visible in the foreground of the photograph. Figs. 14, 15, 16 and



FIG. 16—GOOD DESIGN WITH ROUND FLANGE IN CENTER AND SMALL BOSS TO RIGHT.

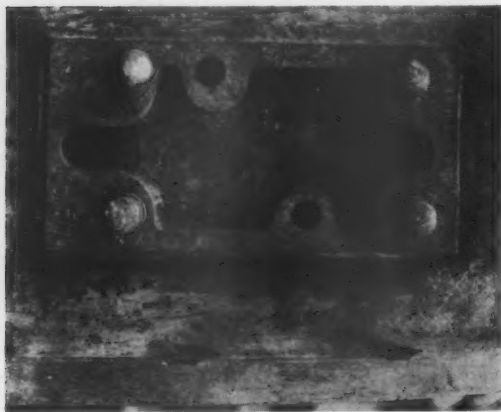


FIG. 17—LARGE BOLTING PAD AVOIDING SHARP CORNERS BY CORING OUT THE PAD.

17 give details of this casting or examples that would be applicable to such a design.

37. In Fig. 14 note the care taken to avoid inequalities of section on the projections shown.

38. Fig. 15 shows a large rectangular flange, in the center of the picture, which has been carefully cored out below. Note also the easy rolling ribs and the rounded ridge extending the width of the photograph. This ridge is the outer and top surface of a key-way on the interior of the casting.

39. Fig. 16 shows a round flange in the center of the picture, with a small boss on its right.

40. The last photograph, Fig. 17, is a close view of a large bolting pad, and attention is particularly called to the coring out of this projection and to the fact that sharp corners were avoided in accomplishing this modification.

41. The principles described have been applied in practical production with marked success, and it is hoped that the future will bring even more cooperation between the designer and the producer of castings so that alloys will not be selected solely for their mechanical properties, and that sounder and more serviceable castings will be the inevitable result.

Monorail Materials Handling and the Foundry

BY J. B. FORKER,* CLEVELAND

Abstract

Present conditions in the foundry industry have necessitated the study and adoption of every possible means to reduce costs. One of the best sources of saving is in adoption of efficient materials-handling equipment, especially in foundries where modern high-production methods are in use. In this paper the author outlines the general problem of materials handling in the foundry, discussing the need for and requirements of a successful handling system, stressing particularly the application of overhead monorail materials-handling systems to meet these requirements. Uses for overhead monorails in the foundry are described as follows: Unloading raw materials and transferring to desired location; moving flasks, bottom boards, etc., to and from storage; handling and pouring hot metal; transporting completed molds from molding machines to pouring stations; carrying sand to bins and from bins to molders, core room or conditioners; transporting castings from floor to tumblers, sandblast cabinets and grinders; handling castings in sandblast cabinets; delivering finished castings to shipping room, weighing, and placing them on loading platform. In addition to above, many other special uses of monorail are described, including its use for window washing and building cleaning.

INTRODUCTION

1. A long time ago someone discovered the simple little equation that gross income minus cost, equals profit. Since that day keen minds have been studying continually to make gross income larger and costs lower. The latter, however, is the more important of the two because, if costs are low (other things being equal) the demand stimulated by low prices, possible through low costs, will build gross income. Present conditions, which have forced a substantial reduction in gross income, particularly in

* Sales Manager, Materials Handling Division, The Osborn Manufacturing Co.

foundries, emphasize the necessity for lowered costs so that the profit side of the equation may remain a plus quantity.

2. A study of the factors involved has brought to light some interesting points. Among these, nothing stands out so prominently as the fact that old methods do not work now as well as formerly. There is business to be had, but the competition is keen and the average executive of today, in order to produce profits, must be ever alert to take advantage of every saving possible through the use of new methods and modern equipment.

3. Statistics support the common knowledge that business in the foundry industry has fallen off to a point about as low as any recorded. This may be accounted for in several ways. Added to the general business depression, which has affected all industries alike, the foundryman has had competition from new industries continually invading his field, such as pressed steel, welding and forgings. He has been slow in organizing to advertise the merits of his product. The foundry is one of the oldest of the metal-working trades and precedent has been hard to overcome. The newer metal-working trades, with a minimum of precedent, have taken over easily new, practical ideas to advantage.

IMPORTANCE OF MATERIALS HANDLING TO THE FOUNDRYMAN

4. Industry in general, for the last decade or so, has been striving constantly to perfect new machinery that will turn out more work in less time. This has brought about automatic and semi-automatic machines almost human in their processes, producing more parts or turning out more molds per unit of time and doing a better job than if done by hand.

5. Also, the use of production machinery has brought up many new problems. One of the most important has been the problem of conveying materials to the machines and away to the next process efficiently.

6. Thus, in the growth of mass production a new industry has arisen—the Materials Handling Industry. It has made itself felt through the use of cranes, hoists, roller conveyors, continuous conveyors, belt conveyors, power-driven and hand-pushed floor trucks, sand-handling systems, industrial railways, motor-driven and hand-pushed monorail systems, etc.

7. Let us analyze manufacturing costs briefly at this time,

and see how these tools of industry became important. Manufacturing costs may be broken down to include the cost of material, direct labor, and indirect labor. The latter usually is placed in general shop overhead; however, it is a big item and important enough to be considered in a class by itself. We are concerned only with direct and indirect labor in this paper.

8. At first glance direct labor may seem to be little concerned with materials-handling machinery, but it is. Direct labor can do more productive work of a better quality if it can use its head more and its back less. In the foundry industry this means better molds, lower scrap loss and, consequently, a lower cost per ton of finished castings. The average foundry has too much hard work in it to produce a quality product.

9. Indirect labor for the most part can be charged to management inefficiency. Of course, it is realized that direct labor must have supervision and that the plant must be kept in running order, but we venture to say that the average foundryman with a little careful study could lower his costs considerably. Get indirect labor over into productive work, replace it with machinery where practical, and costs will come down.

10. Many foundries have come from humble beginnings. As they grew and more and more work came in, a man was employed to lug flasks in, then another man here and another there to do odd jobs, important at the time. Precedents were established, and as the plant expanded these little practices became lost in the maze of details and were overlooked. One favorable result of this depression has been to bring a good many of these inefficiencies out into the light where we can get a good, square look at them. But have we got them all?

11. There is an old saying that "A man's knowledge is no better than his source of information." Let me urge foundrymen to familiarize themselves with all classes of materials handling machinery and get their information from reliable sources. Each class of materials-handling machinery has its uses, peculiar to some specific problem, and each has advantages which may be desirable for a particular case.

12. There is no one "cure-all" to lower costs. There are too many variables involved, such as the tonnage, type of building, type of product, present equipment, layout of foundry, size and weight of flasks, and a dozen other things. Each foundry

requires an individual study to secure the best solution. No one is more interested in making such a study than the foundrymen.

13. Some good general rules to observe in planning handling systems are as follows:

- (a) Keep the method as simple as possible.
- (b) Use standardized equipment built by responsible manufacturers.
- (c) Avoid multi-handling. Pick up the load where it is and take it to its destination on one system, then set it down.
- (d) Have an alternative plan of handling that can be used when the main system is out for repairs.
- (e) Determine an economical load, or amount to handle at one time. Set a proper production unit.
- (f) Don't back-track. Keep the flow of material in one general direction, and the distance traversed at a minimum.
- (g) Select the type of equipment that is most flexible and economical for the demand that will be made on it.
- (h) Plan on periodical inspection and maintenance. This is a necessary tool of production.
- (i) Purchase materials-handling machinery for savings, not for initial investment.

GENERAL DISCUSSION OF MONORAIL

14. In line with the writer's own experience, and because he knows more about the overhead monorail than other systems, he shall discuss monorail, endeavoring to give the discussion fair treatment that will reveal its weaknesses as well as good points.

15. Monorail systems derive most of their advantages from the fact that they operate overhead. Here the material travels in a normally unused part of the shop where there is no congestion, permitting fast transportation and storage facilities that increase the efficiency of shop areas. Aisles and passageways therefore can be smaller.

16. Any materials-handling problem involves two processes, one of vertical motion, the other of horizontal motion. Equipment that is sufficiently complete in itself to produce both of these functions is, of course, desirable. Examples of this are the lift truck, the continuous system that dips down and up, and the monorail system that has the hoist and trolley combined, and the drop

section with a plain trolley. Thus the monorail is complete in itself to function in the lift and carry part of the handling.

17. Overhead monorail is designed with a flexibility that permits the solution of handling problems throughout the plant. Further, the whole system may be tied together to make a complete transportation plan. With such equipment it is possible to have simplicity, and it permits one type of materials-handling equipment to take care of all needs.

18. Flexibility includes many things. The monorail can go uphill, downhill, turn sharp curves, tie up with elevators, transfer bridges, go through ovens, and be automatically controlled; in fact, a monorail system can be made to fit almost any requirement. However, unless the installation is properly planned, the use is limited and its value approaches so many pounds of steel. Materials can be moved economically wherever the system operates, but not beyond its limits.

19. Here is where portable floor equipment excels, in that such careful planning is not required. However, all manufacturers are endeavoring to get straight-line flow and to have material travel in definite paths. If this is possible in your own plant you are indeed fortunate, because the planning of a monorail system is then easy and well worth while.

20. The use of overhead monorail equipment simplifies the problem of having an alternative plan of handling, in that it leaves the aisles and floors clear to go back to more primitive methods when necessary. Lack of an alternative plan may mean a shutdown.

21. The maintenance on overhead monorail is very low. This is due in large measure to the fact that dust conditions are less severe overhead than on the floor. All machinery has the faculty for getting out of order occasionally. Overhead monorail systems have but few moving parts, such as the trolleys and switches. Thus, there are few parts to wear out, and consequently the maintenance is negligible.

22. With overhead monorail it is possible to keep multi-handling at a minimum. The same equipment that picks up the load can be used to transport it to its destination. In regard to multi-handling, simplicity and flexibility, an illustration can be cited of a case in a supposedly modern plant which the writer visited some time ago. The chief engineer pointed out with pride his

many ways of handling materials, and he stated that not a man carried material anywhere in his plant. He certainly was materials-handling minded. The writer never before saw so many different types of handling equipment under one roof.

23. However, the engineer was wrong; all that he gained with his clever mechanical methods was lost in the number of men he had to have transporting materials from one system to another. A well-engineered overhead system in that plant would have eliminated about fifteen men and given him the use of more floor space, without considering the maintenance trouble he must have had.

24. Monorail permits the handling of much heavier loads than is either possible or convenient with man power, and at greater economy. This is based on the fact that with proper equipment it is just as easy to handle a heavy load as a light load. It is definitely known that economies are practical from handling larger units of production. While it is known that this is true, to determine the most economical load is not so easy. This must be arrived at through empirical means and practical experience.

25. An item of no small importance to modern industry is floor maintenance. Overhead monorail takes away the bulk of the grinding, abrasive action on the floors. The load travels on a hard, smooth rail with low drawbar pull that is independent of the floors whether they are wood, concrete, gravel, or dirt.

26. With a hard, smooth rail to travel on, overhead systems lend themselves well to handling fragile loads. If necessary the trolleys can be designed to carry the load on springs so as to further minimize shock. Sometimes this is necessary in handling delicate molds or unbaked cores.

27. In planning or purchasing monorail equipment, it always is wise to use equipment designed and built by responsible manufacturers. There are several of these systems on the market today. They are much to be preferred to the home-made systems in that their operating characteristics will be better and their maintenance and service costs lower.

SPECIFIC MONORAIL USES

28. Thus far the writer has discussed, in a general way, materials-handling principles and the advantages of using overhead monorail. In the balance of this paper the writer deals with

some specific problems in the foundry, and shows how monorail may be applied advantageously. The examples cited are, of course, for the purpose of discussion only, and are not intended for actual application without a knowledge of individual conditions.

29. The first handling to be considered is in the yard. Here the raw products of the foundry are received, usually in carload lots. Pig iron, coke, limestone, scrap, sand, alloys, etc., and core-making materials must be unloaded and stored in sufficient quantities to keep the foundry operating. In addition to raw products, the foundry yard usually is the storing place for flasks, bottom boards, bands, and miscellaneous items not affected by the weather but which must be transported to and from the foundry floor.

30. Materials in the yard have three paths into the foundry. The pig iron, coke, limestone, scrap, and alloys go to the cupola charging floor; the sand, flasks, and bottom boards to the foundry floor; core sand and other core-making materials to the core room. Sand may also be relayed to the conditioner.

31. In the handling problems just presented it is desirable to have one system if possible to perform all this work. The same equipment that is used for unloading can be used to transport materials from the yard into the foundry. A motor-operated cab unit, traveling on overhead monorail, can have a detachable magnet for handling pig iron and scrap, a bottom-opening bucket for loose materials, and slings for bulky objects. Care must be taken to have the rail at the proper height for standard railroad clearances, and to have the load high enough to clear the charging platform at the cupola. Thus, the same system may be used for charging the cupola.

32. Loose materials arriving in hopper cars may be dumped into a pit into which the bottom-dumping bucket or clamshell may be dropped for loading. Another plan is to run the monorail directly over the car so that the material can be taken directly from it. The monorail track then is run over the middle of the storage bins; or, if the bins are large, monorail switches are used to allow the use of two or more tracks over the bins. A single line of track through the middle of the yard sometimes is enough to take care of flask storage.

33. The handling of sand is one of the most important problems in the foundry. In the handling of two or more kinds of sand, overhead monorail in many cases is more desirable than

any other system, in that the bottom-opening bucket lends itself extremely well to this situation. The sand has three paths from the storage bins into the foundry: To the foundry floor, the conditioner, and to the core department. Where flexibility of movement such as this is needed, overhead monorail adapts itself readily.

34. The use of monorail in the foundry probably is best known in the handling of hot metal, either for pouring direct into the molds or for distributing to the floors to pour with hand ladles. This method of handling has become quite common practice because of many desirable features, which might be listed as safety, speed in getting the hot metal to the molds, ease in handling, economy, and avoidance of gangway congestion.

35. The pouring layout should have a by-pass or loop in front of the cupola so that the ladles may be filled and taken away to the floor without interference. The empty ladles returning to the cupola can line up on one side, waiting their turn to be filled without interfering with the full ladle leaving from the other side, on its way to the pouring floor.

36. At the molding machine, or on the foundry floor, flasks and bottom boards have to be brought in and taken back to storage. If the copes and drags are large, they are difficult to handle on and off the molding machine to the floor. Also, care must be taken in closing the mold. The farther corners of the floor generally are some distance from the molding machine, and the average distance a finished mold must travel is increasing, due to the higher production of modern molding machines.

37. The sand required by the molder has to be brought to him from the storage bins or the conditioner. In many cases one layout of monorail can be used for all the handling problems on the floor. In using an electric hoist for this job, it is necessary to select one that has variable speed or one that has a slow speed, so that the molds will not be jarred in handling. Single-speed electric hoists give too much shock to the molds in starting and stopping, so that their use here is not practical.

38. There is a growing tendency to handle molds direct to a pouring station and thence to the shakeout grid. A loop monorail layout lends itself well to such a plan. Here a platform is suspended from a monorail trolley. The loop goes by the molding machine, the pouring station and over the shakeout grid, back

to the molding machine. The molder places his mold on the platform and it is moved to the pouring station to be poured, then to the shakeout grid where the molds and castings are dumped. The platform flask and bottom board are returned to the molder as the trolley moves around the loop.

39. The sand from the shakeout has to be taken to the conditioner and the castings to the cleaning room. Both of these are typical monorail jobs. In the cleaning room large castings usually are handled singly, the small castings in tote boxes. These go to the tumblers, the sandblast cabinets, and then possibly to the grinders.

40. The use of monorail to charge and empty tumblers is quite widespread. This speeds up the loading and unloading, permitting more efficient use of the tumbler. The use of monorail in the sandblast rooms also is quite usual. Here the approved method is to support the casting on hooks suspended some distance from the trolleys.

41. The rail, fittings and trolleys are in the top of the sandblast cabinet, where the abrasive action is the least severe. The wear and tear comes principally on the inexpensive hooks where the blast is directed. These are replaced easily and cheaply as required. Then there is a protective coating which has been developed recently by one of the rubber companies in a method of making rubber adhere to steel. Rubber has been found to give the most satisfactory service in the sandblast rooms.

42. Swing grinders are often supported on monorail track, or monorail jib cranes, making it possible to cover a much wider area than with the grinder singly suspended.

43. Overhead monorail has great practical value in transporting castings from the cleaning rooms, through the shipping department, to the loading platform. In the shipping room, scales sometimes are built into the monorail system, permitting the weighing of castings without setting down the load.

44. In the steel foundry, in addition to the above, the castings have to be transported to the soaking pits or annealing ovens. Overhead monorail offers speedy, efficient transportation for such purposes.

45. In the malleable foundry the castings are routed via the annealing ovens, and then on and off the charging cars.

46. A new use of overhead monorail that the foundries are going to take up in the next few years is for window washing and building cleaning. The foundry has too long been a dirty and muggy place to work in, even under the best conditions. The modern executive has learned that good lighting and clean surroundings have much to do with efficiency and morale in the shop. For this use the monorail is suspended under the eaves on the outside, and above the windows on the inside of the shop. Running on the rail is a trolley carrying a chain hoist and an enclosed cage from which the window washer works. Thus the difficult and dangerous job of cleaning up is made safe and much more economical.

47. From a full consideration of the many problems discussed, it can readily be understood that there is a real basis for statements of authorities that from 150 to 200 tons of materials are handled to produce one ton of finished castings. Also, it can readily be appreciated how badly the foundry industry as a whole needs modern materials-handling machinery to lighten its burden and reduce its costs.

DISCUSSION

ORAL DISCUSSION

CHAIRMAN D. M. AVEY:¹ There has been a popular conception that we are over-mechanized industrially; in fact, that statement has appeared very loosely, being quoted not only by those who should know better but also by those who should not. A writer on financial subjects stated recently that we were perhaps over the peak and headed again to the state where a large part of mechanical development would be unusable due to lack of consumption.

If one stops to think how ridiculous such a statement is, applying it down to the last degree, one could not say where the stopping point would be. Everything we wear or eat or use or ride on would be impossible, and I do not think we are headed back to that condition. Few of us, I know, would care to go back to burlap sacks for footwear.

The foundry industry as a whole is going to realize that its problem is even more acute in that the very factors the author brought out, namely, unpleasantness of surrounding conditions, under certain meth-

¹ Penton Publishing Co., Cleveland.

ods of operation have been alleviated to a large extent in the modern foundry. The automobile people have contributed largely to the advance.

E. W. BEACH:² It would be interesting to know how many shops represented in this meeting have not installed mechanical handling. Are there any such here?

Those of us who have had experience with mechanical handling fully realize that if we had taken as a guide the nine general rules as given by Mr. Forker in his paper, and if we had consulted a man or firm who had devoted much time to specializing in the art of conveying materials, we would have saved ourselves considerable time, grief and expense.

The greatest fault—if there is a fault in mechanical handling—is that which all of us are prone to attempt: Trying to get too much for our money. In the case of motorized handling, we under-power our systems, and for the most part we build our installations too light. Either or both of these errors causes, in the long run, great expense from the standpoint of maintenance.

I believe the thing to do is first to study the conditions thoroughly and then consult the specialist and try to have him protect us against ourselves and our own faulty engineering. After that, if we buy the lighter, cheaper system, we must suffer the consequences and blame only ourselves rather than blame the basic idea of mechanical handling, if the result is not what we had expected.

D. H. WRAY:³ The only experience we have had is in carrying the heavy load coming from the trucks to the bins, and there mechanical handling is a great help, saving the cost of the equipment inside of a month.

JOHN E. LINABURY:⁴ A mistake often made in reference to mechanical handling is the improper selection of equipment, forgetting that it costs money to load and unload conveyors.

Another thing often overlooked in the savings involved with mechanical conveyors is the beneficial effect of getting everybody in step, of speeding up the men. If a man wants to take a chew of tobacco the usual way would be to take it just before the job and hold it back a few seconds. Again, a man will take a moment to turn around or do some personal act when he has an opportunity, thus holding back production.

In cooling the molds it is much more helpful to get everything synchronized, every job working in just the right time. Find the right time and hold to it.

I have seen many cases in the past year or two where mechanical handling would not apply because of very low labor rates. A thing that would apply in this country and show a very beneficial saving, might not show any saving at all on the other side of the Atlantic.

² Engineering Executive, Campbell, Wyant & Cannon Foundry Co., Muskegon, Mich.

³ Vice-President, Henry Wray & Son, Inc., Rochester, N. Y.

⁴ Foundry Engineer, A. J. Brandt, Inc., Detroit.

The labor figure must always be taken into consideration and a careful balance made before any equipment is decided on.

E. W. BEACH: What I meant definitely to call attention to was the value of Mr. Forker's outline, which simply bears out what Mr. Linabury says. As co-laborers we are at present working on just such a problem. It means the changing and alteration of loading and unloading points. The specialist, if he has made a study of materials to be handled, can help us all avoid errors, even if we think we know just what we want. Consultation will save much time and bother.

O. D. CONOVER:² Mr. Forker's ninth point was very well covered, although it occurs to me that probably a tenth might be added, the elimination of personal injuries. Many times these hazards around foundries without the materials-handling equipment, could be almost totally or totally eliminated.

² Vice-President, Foundry Equipment Co., Cleveland.

Melting Iron in Rotary Pulverized-Fuel-Fired Furnace

BY D. J. REESE,* HARVEY, ILL.

Abstract

The construction and operation of the pulverized-coal-fired rotary furnace for melting cast iron is discussed. The temperature of the flame is said to reach 3000 degs. Fahr. without preheated blast, and 3150 degs. Fahr. with the preheated blast. Originally developed for melting malleable cast iron, the furnace is said to be equally applicable for melting various grades of cast iron, producing a uniform product. Comparative costs of furnace linings and data on iron heats are given. Borings up to 75 per cent of the charge were melted. Uniformity of control of the metal quality and flexibility in producing iron of different analyses are stated to be two of the major advantages of this type of furnace.

1. A rotary type of melting unit, fired with pulverized coal, has been in commercial use since the beginning of 1929. Up to the present time approximately 80 rotary furnaces have been installed in Germany, France, England, Italy and the United States.

A Working Installation

2. Fig. 1 shows a 2-ton Brackelsberg furnace installed in a foundry at Birmingham, Ala. This furnace was put into service in November 1930, and at the time this paper was written 407 heats had been melted.

3. The furnace consists of a cylindrical shell fitted with conical ends. Two steel tires support the furnace in the tilting cradle, and through them the furnace gets a rotation motion. A gear segment forms an integral part of the cradle, permitting the furnace to be tilted through an angle of approximately 100 degrees.

4. The complete installation includes a pulverizer, furnace,

* Engineer, Whiting Corporation.

burner, fans, stack and preheater. The small pulverizer shown in Fig. 1 has ample capacity for firing a 2-ton furnace. Firing may be accomplished by a direct-fired pulverizer or by a bin feed in a central plant system.

Primary and Secondary Air Sources

5. The burner has been designed to use air from two sources: Primary air conveys the pulverized coal to the burner; secondary air, which supplies the additional air for combustion of fuel, may be preheated if desired. The pulverized-coal flame approaches an actual temperature of 3000 degs. Fahr. when using room temperature air, but if the air is preheated 600 degrees, the resultant flame temperature will be approximately 3150 degs. Fahr.

6. The amount of air used can be controlled by adjusting the gates on the intake side of the fans. About one-third of the total air required for combustion is used to convey the pulverized coal. Between the furnace and the stack, or in the stack, a recuperator is installed through which secondary air is blown, thereby eliminating water-cooled bearings on the fans.



FIG. 1—VIEW AT FIRING END OF 2-TON FURNACE DURING OPERATION, SHOWING DIRECT-FIRED PULVERIZER WITH FEEDER, PRIMARY AND SECONDARY AIR PIPING, BURNER AND TAPPING SPOUT.

7. Up to the present time no recuperators have been installed on Brackelsberg furnaces in this country, although in other parts of the world about half of the furnaces are equipped with recuperators. Metallic recuperators have been preferred to the refractory type.

Originally Developed to Melt Malleable

8. The rotary furnace originally was developed to melt malleable iron. Since its development, however, it has been found a very convenient melting unit for melting high-test gray iron satisfactorily. The sponsor of the Brackelsberg furnace in this country felt that it satisfied a demand for an economical melting unit for special grades of iron.

Furnace Lining

9. Most of the furnaces have been operating on acid linings, as is used on all the furnaces in this country. The development work on steel melting in Germany has been performed on both acid and basic linings.

10. Some furnaces have been lined entirely with a monolithic lining, others entirely with brick, and some with a combination of brick and monolithic material. The furnace shown in Fig. 1 was lined entirely with a monolithic lining. It was put into service Nov. 4, 1930, and replaced one year later after melting 335 heats or a total of 642 tons of metal.

11. This period covered considerable experimental work, although the furnace was used on production work from the first heat. The period included 321 heats of various types of gray iron, including alloy gray iron, 8 heats using gray iron borings, 4 heats of plain carbon steel and 2 heats of experimental work with manganese ore.

12. Total cost of lining labor and material during this period was \$1.81 per ton of metal melted. This figure is in no way representative of lining costs on regular melting but is included here simply because it is the first furnace of this type which has been in operation long enough to provide any actual operating figures.

13. The second lining on this furnace will furnish us with practical figures on the refractory cost. At the time this paper

was written, the furnace has had 72 heats on the second lining. Estimates of refractory costs, based on performance of the first lining, indicate less than \$0.50 per ton of metal melted. The second lining is a combination of brick and monolithic material. Lining costs on the first lining were affected largely by experimental work with high-temperature cements, this item amounting to \$532.00 for 11,200 lbs. of cement.

Operation of Furnace

14. Fig. 2 shows the furnace in the charging position; one heat has just been tapped. Slag from one heat is dumped from the furnace as it is moved to the charging position for the next heat. Charging of the furnace may be by hand or with mechanical charging equipment, the furnace shown in Fig. 2 being hand charged. After charging, the furnace is tilted to the horizontal position for firing. It can be moved 10 degrees under the hori-



FIG. 2—TWO-TON FURNACE IN CHARGING POSITION. SLAG FROM HEAT IS DUMPED FROM FURNACE WHILE FURNACE IS MOVED TO CHARGING POSITION FOR NEXT HEAT.

zontal position for tapping and 90 degrees above it to the vertical position in which it is lined.

15. If the furnace is cold, a wood fire is started before starting the fans and the pulverizer. The lining temperature on second, third and fourth heats is sufficient to ignite the coal without a wood fire. The 2-ton furnace has been fired with 460 to 480 lbs. of coal per hour.

16. The furnace remains stationary until the cold charge is almost melted down, approximately 65 per cent of the entire charge being fluid when rotation is started. Rotation is through a complete circle and may be either clockwise or counter-clockwise. Our practice has been to run the furnace in one direction on one heat and reverse the direction on the next heat.

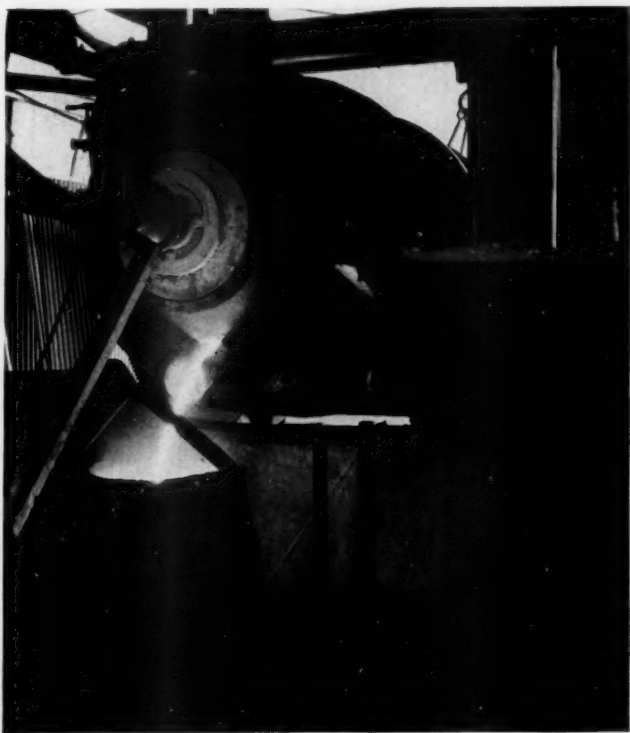


FIG. 3—TAPPING A 2-TON FURNACE. METAL AT SPOUT, 2840 DEGS. FAHR.

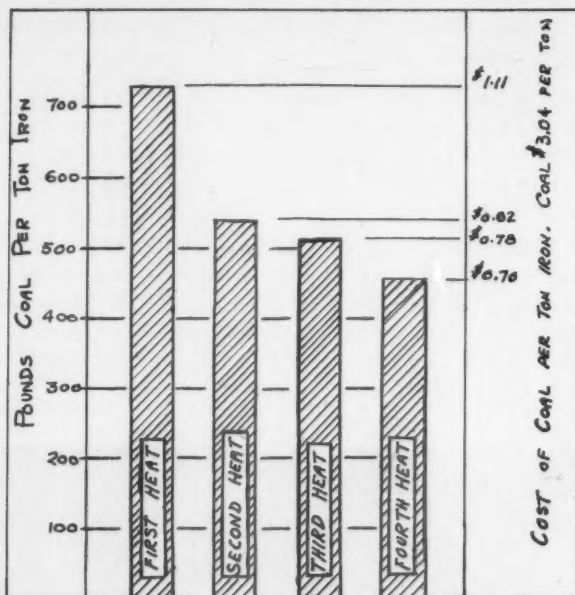


FIG. 4—FUEL COSTS AND AMOUNT USED IN 2-TON FURNACE FOR FIRST, SECOND, THIRD AND FOURTH HEATS PER DAY.

17. The metal temperature is approximated by knowing the length of time the furnace has been under fire. Actual spoon tests and fracture tests can be taken for temperature and fracture examination. Our practice has been to take optical temperature readings on the lining at the rear of the furnace, as the metal temperature will be very near that of the lining.

18. Any alloy additions can be made just before the heat is tapped. This is done with the furnace in operation, the alloys being added at the rear of the furnace.

19. Fig. 3 shows the furnace being tapped. Metal temperature on this heat was 2840 degs. Fahr. The tap spout may be located on either the front or rear cone, or on the shell. The tap spout may be opened and plugged as in cupola practice, or the tap spout may be kept open and the furnace rotated until the spout is above the metal line. It also is possible to dump the entire heat at one time with a pit and crane ladle at the rear of the furnace.

Pulverized Coal Used

20. The furnace is fired with pulverized coal, and it is desirable to have a good quality of coal which may be purchased as slack size. Good quality coals are available from the West Virginia, Kentucky and Pennsylvania fields at \$0.60 to \$1.25 per ton. Fig. 4 shows the fuel consumption per ton of iron melted when melting one, two, three or four heats per day in a 2-ton furnace.

21. These figures are taken from furnace records at Birmingham. This coal cost \$2.25 per ton at the mines with a freight rate of \$0.79 per ton. A car load of Pennsylvania coal was shipped from the Westmoreland district to check against the Alabama coals, and melting costs were found to be the same for both coals.

22. The coal should be fine enough so that 82 to 85 per cent will pass through a 200-mesh screen and 100 per cent pass through a 40-mesh screen. A metallurgical coal should be low in sulphur (less than 1.25 per cent) and low in ash (less than 10 per cent). In general, the volatile matter will be around 33 to 35 per cent, although Alabama coals range from 28 to 30 per cent. It can be safely stated that the higher the quality of coal, the better will be the over-all efficiency.

Data on Heats

23. Table 1 gives data on a series of 9 heats in which the steel content of the charge was approximately the same. These data are not offered as the ultimate goal possible, but merely to suggest the uniformity obtainable in duplication work. The test data were compiled by the Pittsburgh Testing Laboratories on work done by them on standard A. S. T. M. bars.

24. Fig. 5 shows two photomicrographs, one etched and one unetched, of a type of iron of which several hundred tons have been melted. The chemical, physical and metallurgical work was done through the courtesy of the Stockham Pipe and Fittings Co., Birmingham, Ala.

25. Table 2 illustrates what may be expected in metallurgical losses when holding a very fluid bath after pouring temperature has been attained. Sample A is the analysis of a 3000-lb. heat. After tapping out 1000 lbs., 200 lbs. of steel were added; sample

Table I
DATA ON A SERIES OF NINE HEATS TO GIVE ONE CLASS OF METAL

	Heat Numbers									
	87	89	91	94	95	100	103	105	106	
Per Cent Steel in Charge.....	12.4	12.4	12.4	13.3	13.3	11.0	13.3	12.4	15.0	
Silicon, %.....	1.91	1.99	2.09	2.02	2.08	1.70	1.59	1.96	1.95	
Manganese, %.....	0.58	0.61	0.54	0.56	0.57	0.55	0.40	0.45	0.60	
Phosphorus, %.....	0.53	0.52	0.50	0.57	0.54	0.56	0.51	0.53	0.47	
Sulphur, %.....	0.066	0.060	0.063	0.069	0.067	0.069	0.063	0.063	0.064	
Total Carbon, %.....	2.83	2.82	2.74	2.70	2.74	2.99	2.99	2.88	2.90	
Combined Carbon, %.....	0.67	0.69	0.73	0.68	0.68	0.77	0.64	0.74	0.63	
Nickel, %.....	.....	.....	.....	.....	.....	2.86	.....	.....	.....
Molybdenum, %.....	.....	.....	.....	.....	.....	.....	.....	0.44	.....
Transverse Strength:										
Bar No. 1, lbs.....	2860	3250	3040	2280	3000	2830	2950	4175A*	2800	
Deflection, in.....	0.23	0.26	0.26	0.19	0.23	0.22	0.25	0.12	0.23	
Bar No. 2, lbs.....	2500	2870	2520	2635	3360	2515	2880	3925A*	2565	
Deflection, in.....	0.20	0.24	0.21	0.23	0.18	0.22	0.29	0.11	0.22	
Bar No. 3, lbs.....	2390	2980	2290	2600	2640	2710	2700	2620	2600	
Deflection, in.....	0.20	0.22	0.19	0.21	0.20	0.23	0.23	0.19	0.22	
Bar No. 4, lbs.....	2840	2875	2720	2800	2960	2400	3000	3000	2340	
Deflection, in.....	0.22	0.25	0.24	0.23	0.22	0.18	0.25	0.23	0.18	
Tensile Strength, lbs. per sq. in.:										
Bar No. 1.....	43,240	.....	.....	.....	.....	.....	.....	46,460	.....
Bar No. 2.....	39,690	43,200	43,090	43,620	43,020	40,250	38,600	43,460	39,140	
Bar No. 3.....	.....	42,720	41,960	44,470	45,800	34,640	40,990	.....	39,280	
Brinell Hardness:										
Bar No. 1.....	235	.....	.....	.....	.....	.....	.....	241	.....
Bar No. 2.....	235	235	235	217	233	241	217	241	228	
Bar No. 3.....	.....	241	228	235	241	235	212	.....	241	

*A—Old A. S. T. M. standard of 1.25-in. bar on 12-in. centers.

B is the analysis of this metal after holding one-half hour. A second 1000 lbs. was tapped out and 100 lbs. of steel added; sample *C* is the analysis of this material at the end of one-half hour.

Use of Borings

26. A number of heats were melted in which borings were used as part of the furnace charge. Our work has varied, using from 25 to 75 per cent of the charge in borings; borings weighed 160 lbs. per cubic foot.

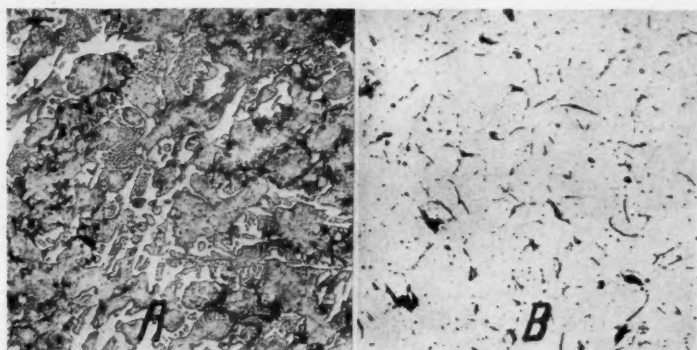


FIG. 5—PHOTOMICROGRAPHS OF IRON MIXTURE MADE IN 2-TON FURNACE. ANALYSIS: Si 1.16, Mn 0.60, S 0.064, P 0.217, TC 3.45, Cr 0.35, Ni 0.20. BRINELL HARDNESS 248, TRANSVERSE STRENGTH 4865 LBS. ROUND BARS TESTED ON 12-INCH SUPPORTS, TENSILE STRENGTH 33,450 LBS. PER SQ. IN. A: UNETCHED SAMPLE, X100. B: SHOWING SORBITIC, PEARLITIC AND CEMENTITE STRUCTURE. ETCHED IN CONCENTRATED NITRIC ACID, X100.

Table 2

ANALYSIS OF FURNACE METAL AT $\frac{1}{2}$ -HOUR INTERVALS, WHEN STEEL AND FERROSILICON ARE ADDED TO SECURE PROPER TONNAGE IN FURNACE

	Melt "A"	Melt "B"	Melt "C"
Silicon, per cent	2.76	2.85	2.66
Sulphur, per cent	0.052	0.056	0.063
Phosphorus, per cent	0.206	0.204	0.202
Manganese, per cent	0.42	0.40	0.39
Graphitic Carbon, per cent	2.04	1.70	1.43
Total Carbon, per cent	2.64	2.41	2.21

NOTE: Melt "A:" original melt. Melt "B:" 10 per cent steel rails added to replace used metal of "A;" ferrosilicon also added. Melt "C:" 10 per cent steel rails added to replace used metal of "B;" ferrosilicon also added.

Table 3
HEATS WITH BORINGS

	Analyses of Metal in Charge* and Casting							
	25% Borings		40% Borings		50% Borings			
	Heat Number		Heat Number		Heat Number		Heat Number	
	59	127	155	90				
	Charge	Heat	Charge	Heat	Charge	Heat	Charge	Heat
Silicon, %.....	2.00	1.59	2.88	2.15	3.19	2.50	2.02	1.60
Manganese, %.....	0.64	0.43	0.50	0.36	0.84	0.70	0.61	0.31
Phosphorus, %.....	0.50	0.50	0.70	0.71	0.70	0.76	0.53	0.59
Sulphur, %.....	0.050	0.076	0.058	0.068	0.056	0.085	0.063	0.084
Total Carbon, %....	3.36	2.82	3.56	2.81	3.56	2.91	3.26	2.33
Physical Composition of Metal Charged								
Borings, %.....	25	40	40	50				
Steel, %.....	6.6	.....	.....	6.7				
Scrap, %.....	11.7	.....	.....	.....	
Pig Iron, %.....	56.7	60	60	43.3				
Metal Charged, lbs.	3000	4260	4620	3000				
Metal Poured, lbs..	2964	3975	4260	2870				
Loss, %.....	1.2	6.7	7.8	5.4				

* Accurate analysis of borings not known. Above figures on charge analysis are based on average figures in this plant.

27. The use of any quantity of borings greater than 10 per cent introduces an unknown factor unless the user of the borings is absolutely certain of the analysis. Our boring tests were conducted with an accumulation of machine-shop borings, kept under cover but collected over a long period of time from a variety of work. Furnaces have been operated abroad with 100 per cent borings and 100 per cent steel turnings.

Types of Metal Melted

28. The charges used in the 2-ton furnace at Birmingham have varied over a wide range. For example, we have melted 100 per cent steel rails and also 100 per cent pig iron. This should serve as a good guide to the flexibility of the melting unit.

DISCUSSION

ORAL DISCUSSION

CHAIRMAN H. W. GILLET:¹ It has been interesting to me to follow foreign comment on the rotary furnace development. It seems rather a unanimous opinion abroad that this is a useful tool, giving uniform results, and that with proper charges it can be made to give uniformly high quality.

¹ Director, Battelle Memorial Institute, Columbus, Ohio.

On some parts of the Continent foundrymen probably are not in quite so receptive a mood for electric melting as we are in this country, and this present development seems a good intermediate step for getting high-temperature melts. I imagine that the electric furnace will go higher in temperature than this rotary furnace if the higher temperatures are required, but certainly the latter furnace will be more flexible in the preparation of high-test iron than is the cupola, because of its greater ability to handle high temperatures.

I have noticed the foreign competition on melting costs and have tried to transfer them to our own situation. While it must not be forgotten that a pulverizing cost must be added to the cost of cheap bituminous coal, the rotary furnace does seem to figure up, on fuel cost alone, to be certainly competitive and probably somewhat ahead of cupola operation in the average locality.

MEMBER: What is the time of melting down the first charge as compared with that of the second charge, for a 2000-lb. furnace? I understand that you start with a cold charge.

D. J. REESE: These furnaces are built in several different sizes of cold-charge capacity of 2, 5 and 10 tons. The hourly melting capacity on a 2-ton furnace is approximately one ton per hour, between fifty and sixty minutes being required to melt a ton of metal. On the 5-ton furnace the hourly capacity is $1\frac{3}{4}$ tons; on the 10-ton furnace, $2\frac{1}{2}$ tons.

These figures are for room-temperature air. When the air is preheated to 800 degs. Fahr., the melting rate is approximately 20 per cent faster. These figures also are quoted using the firing rate on which we have started out. This furnace has a firing rate of approximately 500 lbs. of coal per hour. It is speeded up about 10 per cent by firing a little more heavily, at around 600 lbs. of coal per hour.

In starting a furnace cold after the furnace has been lying idle over a week end, the time required to melt the first heat is approximately 50 per cent greater than the time required on second or third heats. If the furnace has been in operation during the week and has shut down overnight, the first heat takes about 25 per cent longer than the second or third heat.

MEMBER: Has the author ever tried taking off a heat in the furnace without rotating it—simply charging the metal in and putting the heat on? If so, what would be the difference in the result between doing it that way and rotating it? In other words, just what is the advantage of the rotation? Without that it would be simply an air furnace.

D. J. REESE: We have not operated the furnace stationary throughout a whole heat, but in operating a furnace as a rotary furnace, in taking a hot roof and making a hot bottom, the factor of time and economy speeds up considerably. One gains some idea of the economy of rotation by considering the following facts.

An air furnace of even large capacity (15 or 20 tons), melting at least two heats a day, would give good economy if three pounds of iron were melted with one pound of coal. Using a 2-ton rotary furnace, which is only one-eighth the capacity of a 15 or 20-ton air furnace, one can

melt four pounds of iron with one pound of coal. By rotating a furnace and making the bottom just as hot as the roof, the depth of the melt is effectively made only one-half; there is twice as much hearth area available for heat transfer.

When we add ferrochrome, we never add chrome until the bath is up around 2800 degrees. Then, by rotating the furnace and adding chrome a few minutes before tapping, we work the chrome in very well.

Accordingly, there would be no reason for running a rotary furnace as a stationary furnace, because it is much more efficient thermally as a rotary furnace than it would be as a stationary furnace. Trying to operate small air furnaces of 2-ton capacity would be almost outside the capacity of a stationary furnace.

DR. FRITZ MEYER:² As to the influence of the rotating action on a powdered-coal-fired furnace, besides the advantage of speeding up melting, or of getting greater fuel economy and of prolonging the life of the melting (as Mr. Reese has explained), there is a considerable advantage in rotating the furnace on account of the mechanical cleaning action. Several foreign institutes have worked along this line and have found that, in any case, material of the same chemical composition and the same physical properties made in the rotating powdered-coal furnace, showed greater machinability in comparison with cupola or with the stationary air furnace. The only explanation that can be given is the fact that rotation of the furnace permits the mechanical removal of inclusions which act as abrasives, by giving them an opportunity to combine with the slag.

I believe the biggest advantage of this type of rotary powdered-coal furnace lies in the possibility of using it as a salvaging furnace. Instead of being satisfied with producing only a commercial cast iron or a synthetic pig iron out of borings, turnings and other grades of cheap scrap, this furnace offers a possibility to use the same cheap product and yet end up with an iron of high physical properties.

Operation of this furnace permits close analysis control. If for example, the foundryman does not know the chemical composition of his scrap, cast-iron borings and steel turnings being charged, he has the opportunity of taking samples for preliminary analysis right after the material is molten. Also (as the speaker explained), by proper adjustment of the ratio of powdered coal to air he can keep the furnace on temperature without materially changing the chemical composition.

It must be remembered that, without changing the chemical composition, there always will be a slight loss in carbon but none in silicon. Of course, during melting down there always will be a slight oxidation, but the oxidation is so small that it is of no practical consequence. When the iron reaches the liquid state (showing, for example, too low carbon and too low silicon), it can be brought up to the desired analysis by recarburizing with petrol coke and by means of added ferrosilicon. If the silicon is too low and the carbon too high, silicon can be added to the furnace; to get carbon down to percentages wanted, steel can be added.

Recently I had an opportunity to work on a furnace similar to the

² Consultant, Rockford, Ill.

Brackelsberg furnace. Experimental work was done with the purpose of getting a furnace which increased melting capacity and permitted continuous melting. The advantage of close control over chemical composition has made this problem, or the solution of this problem, quite easy.

I have prepared a table (see Table 4) showing the chemical composition over a period of a few hours, running continuously. Every time iron was tapped from the furnace, the same amount of cold material was charged in the furnace. Charging takes place at the end opposite the burner and the spout.

I wish here to advance a statement about too close control of the chemical composition, which sounds nearly impossible. We all know that, for example, a laboratory may run the analysis on silicon perfect and the result will vary just the same—approximately plus or minus 0.05 per cent. It is just a coincidence that has shown the silicon practically the same all the time.

In Table 4 the left-hand column shows the time when the furnace was tapped, 800 lbs. being removed each time. At the same time, as

Table 4
HEAT No. 43—36,500 LBS.

Elapsed Time.	Ladle No.	Si %	S %	P %	Mn %	TC %
	1	2.21	0.072	0.227	0.81	2.90
35 min.	4	2.20	....	....	0.85	2.91
1 hr. 20 min.	7	2.20	0.076	....	0.82	2.89
1 hr. 42 min.	11	2.21	....	0.233	0.82	2.89
2 hrs. 20 min.	19	2.19	....	....	0.78	2.88
2 hrs. 46 min.	23	2.22	0.079	....	0.74	2.86

mentioned before, the same weight of iron was charged to the furnace. The silicon and carbon control varies here only about 0.05 per cent.

Table 5 shows chemical composition, physical properties and mixture of the iron shown in the photomicrographs of Fig. 6.

These micrographs show, in addition to fine graphite precipitation and pearlitic structure, a tendency toward formation of cementite. It will be realized that this kind of structure, if produced in a stationary furnace, would cause difficulties in the machine shop. Very likely the mechanical cleansing action, as mentioned before, has washed out most of the abrasive inclusions, for which reason this material has machined in accordance with the standards set for machinability in automotive shops.

Since the advantageous influence of superheating in accordance with the nuclei theory has been discussed already at this convention, there is no need of repeating it. In my opinion, the rotary powdered-coal furnace compares favorably with the highest-type stationary furnace such as the electric furnace.

It has been mentioned that only two rotary pulverized furnaces are in actual production in this country. To my knowledge there are approxi-

Table 5

SAMPLE No. 11

Physical Properties:

Transverse strength, 1.2 in. diam. on 12-in. centers	5952 lbs.
Deflection	0.16 in.
Tensile strength	53,620 lbs.

Analysis:

Si	2.46
S	0.095
P	0.285
Mn	0.40
TC	2.69

Charge:

Pig	10%
Remelt	30%
Steel	20%
Gray iron scrap	40%
Degs. Fahr.	2873

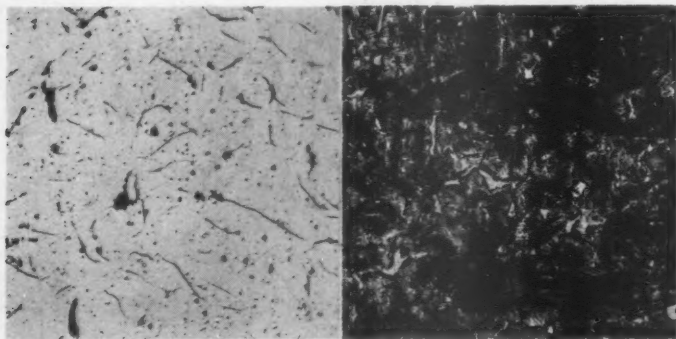


FIG. 6—PHOTOMICROGRAPHS OF IRON OF TABLE 5. *Left*: UNETCHED, X100.
Right: ETCHED, X100.

mately 70 powdered-coal rotary furnaces of different makes in actual production in Europe, and I am positive that the developments mentioned by the author and those of the Beardsley & Piper Co. in producing material of different types in rotary powdered-coal furnaces, individually designed for their purposes—cold batch, continuous operation from cold charge, or duplexing—will result in foundries being able to secure a furnace for production of high-quality material, with simplicity of operation, at low cost.

Effect of Thermal Treatment on the Characteristics of Black-Heart Malleable Iron

By TARIO KIKUTA,* Tokyo, Japan

Abstract

If completely annealed black-heart malleable iron castings are given certain heat treatment, as in the case of galvanizing, the castings become very brittle at room temperature. Studies by Marshall showed that by quenching the castings from 650 degs. Cent. (1202 degs. Fahr.) before galvanizing, embrittlement could be prevented. The author's studies confirmed Marshall's work, but the author continued his study to find an ideal annealing. He presents data to show that castings produced by his method are not subject to galvanizing embrittlement even though they have not received the Marshall treatment. Detailed experiments are listed and the results tabulated and discussed. As a final section of the paper, the author presents his theory of the embrittlement of malleable cast iron.

INTRODUCTION

1. If completely annealed black-heart malleable iron castings are thermally treated, as in the case of galvanizing, the castings become very brittle at room temperature. Fractures are white with a metallic luster. Leslie H. Marshall studied this problem and later published his results.¹ The writer also studied the problem at about the same time.

* Director, Research Laboratory, Tobato Foundry Co.

¹ Bureau of Standards, Tech. Paper No. 285, 1923; *Iron Age*, Feb. 25, 1926, also *Foundry*, March 15, 1926.

2. Marshall's investigation consisted of a series of impact tests on specimens of black-heart malleable cast iron quenched from various temperatures. He found that if castings are cooled in water from temperatures ranging from 300 to 550 degs. Cent. (572 to 1022 degs. Fahr.), they become brittle. He also discovered that by quenching castings from 650 degs. Cent. (1202 degs. Fahr.) before galvanizing, embrittlement could be prevented.

3. In the course of the writer's research, Marshall's results have been duplicated, but continued study has been made in order to find an ideal annealing method for the production of superior malleable cast iron from white-iron castings. Malleable-iron cast-

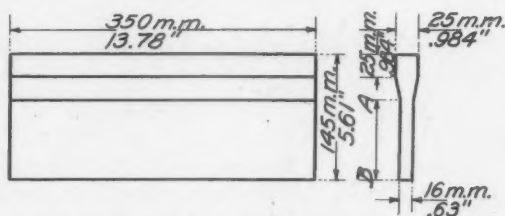


FIG. 1—IMPACT SPECIMENS WERE MACHINED FROM THE SECTION A-B.

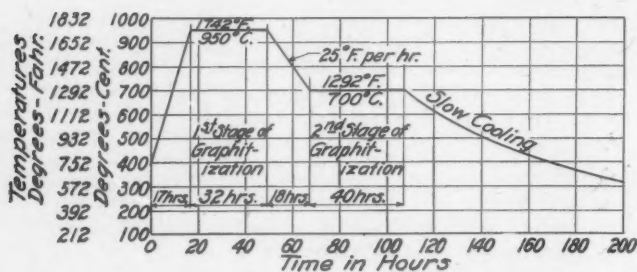


FIG. 2—ANNEALING CYCLE USED IN PREPARING SPECIMENS.

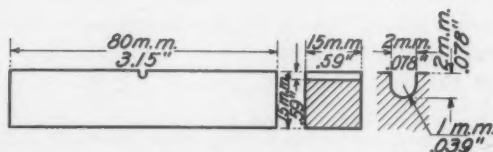


FIG. 3—MODIFIED CHARPY SPECIMEN USED FOR IMPACT TESTS.

ings produced by the writer's method are not subject to embrittlement during galvanizing even though they have not received the treatment as recommended by Marshall.

4. The writer made impact tests at various temperatures on untreated and thermally treated malleable specimens, and resistance measurements during heating and cooling. From these data was evolved a theory for the embrittlement of black-heart malleable cast iron.

5. The specimens for these particular tests were comparatively high in carbon, high-carbon material being selected in order to obtain sound castings readily. The chemical compositions of the two white irons used are as follows:

No. of Material.	Heat No.	C	Si	Mn	S	P
O	8E-3344	2.86	0.92	0.33	0.045	0.146
A	8E-3346	2.86	1.01	0.27	0.048	0.154

6. More than one hundred white-iron specimens (see Fig. 1) were cast in green sand and carefully annealed in an electric furnace. The annealing cycle is shown by the curve in Fig. 2. In order to obtain complete graphitization of the cementite, the period of high temperature was divided into two stages.²

7. The annealed castings were machined on two sides to a thickness of 15 mm. (0.59 in.) and cut into impact specimens to dimensions as shown in Fig. 3.

EFFECT OF HEAT TREATMENT ON IMPACT VALUE OF BLACK-HEART MALLEABLE CAST IRON

I—A Relation Between Temperature and Impact Value for Specimens Quenched in Water from Various Temperatures.

8. The specimens were held at various high temperatures for 20 minutes, followed by cooling in water. After this heat treatment the specimens were broken in a 30-kg.m. (217-ft. lb.) Charpy impact testing machine* at room temperature (9 degs. Cent.—48 degs. Fahr.) The impact values obtained are tabulated in Table 1 and shown graphically in Fig. 4.

²T. Kikuta, "On the Malleable Cast Iron and the Mechanism of Its Graphitization," *Science Report, Tohoku Impl. Univ.*, vol. 15, no. 2, 1926.

* EDITOR'S NOTE: The Charpy impact specimen common to the U. S. A. is 0.394 in. square with 0.234 in. under the notch, while Kikuta's specimen is much larger, being 0.59 in. square with 0.51 in. under the notch; so that the effective section is more than three times as large.

Table 1

No. of Specimen	Heat Treatment	Charpy Impact Value		Fracture
		Kg.m.	Ft.-Lbs.	
1	No heat treatment.....	2.861	20.6	Black
1		3.503	25.3	
2	Cooled in water from 50°C. (122°F.).....	3.223	23.3	"
2		3.503	25.3	
3	Cooled in water from 100°C. (212°F.).....	3.503	25.3	"
3		4.086	29.5	
4	Cooled in water from 150°C. (302°F.).....	3.168	22.8	"
4		3.947	28.5	
5	Cooled in water from 200°C. (392°F.).....	2.005	14.5	Mottled
5		2.264	16.3	
6	Cooled in water from 250°C. (482°F.).....	1.073	7.7	White
6		1.276	9.2	
7	Cooled in water from 300°C. (572°F.).....	0.904	6.5	"
7		1.046	7.5	
8	Cooled in water from 350°C. (662°F.).....	0.598	4.3	"
8		0.741	5.3	
9	Cooled in water from 400°C. (752°F.).....	0.415	3.0	"
9		0.586	4.2	
10	Cooled in water from 450°C. (842°F.).....	0.361	2.6	"
10		0.598	4.3	
11	Cooled in water from 500°C. (932°F.).....	0.586	4.2	"
11		0.598	4.3	
12	Cooled in water from 550°C. (1022°F.).....	0.841	6.1	Mottled
12		0.904	6.5	
13	Cooled in water from 600°C. (1112°F.).....	3.986	28.8	Black
13		4.185	30.2	
14	Cooled in water from 650°C. (1202°F.).....	4.347	31.4	"
14		4.531	32.5	
15	Cooled in water from 700°C. (1292°F.).....	4.387	31.6	"
15		4.738	34.2	
16	Cooled in water from 750°C. (1382°F.).....	4.286	30.9	"
16		4.697	34.0	
17	Cooled in water from 800°C. (1472°F.).....	1.166	8.4	White
17		1.347	9.7	

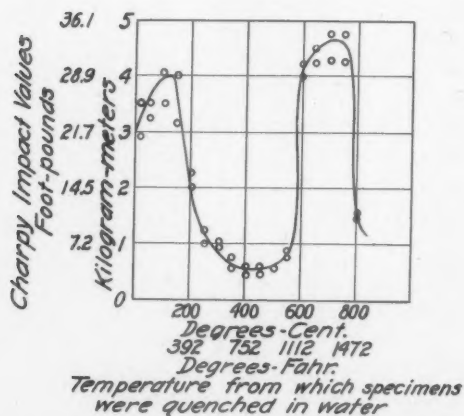


FIG. 4—SHOWING A RELATION BETWEEN TEMPERATURE AND IMPACT VALUE FOR MALLEABLE SPECIMENS QUENCHED IN WATER FROM VARIOUS TEMPERATURES.

Table 2

No. of Specimen	Heat Treatment	Charpy Impact Value		Fracture
		Kg.m.	Ft.-Lbs.	
18	No heat treatment.....	3.408	24.7	Black
18		3.316	23.9	"
19	Cooled in air from 50°C. (122°F.).....	4.185	30.2	"
19		2.430	17.6	(Black but small flaw)
20	Cooled in air from 100°C. (212°F.).....	3.694	26.7	Black
20		3.408	24.7	"
21	Cooled in air from 150°C. (302°F.).....	4.186	30.2	"
21		3.790	27.4	"
22	Cooled in air from 200°C. (392°F.).....	3.315	23.9	Mottled
22		2.600	18.8	"
23	Cooled in air from 250°C. (482°F.).....	2.600	18.8	"
23		1.139	8.2	"
24	Cooled in air from 300°C. (572°F.).....	1.563	11.2	"
24		1.417	10.2	"
25	Cooled in air from 350°C. (662°F.).....	1.276	9.2	White
25		1.073	7.7	"
26	Cooled in air from 400°C. (752°F.).....	1.073	7.7	"
26		1.006	7.2	"
27	Cooled in air from 450°C. (842°F.).....	1.207	8.7	"
27		1.073	7.7	"
28	Cooled in air from 500°C. (932°F.).....	1.207	8.7	"
28		1.139	8.2	"
29	Cooled in air from 550°C. (1022°F.).....	4.387	31.6	Black
29		3.986	28.8	"
30	Cooled in air from 600°C. (1112°F.).....	5.335	38.5	"
30		4.489	32.4	"
31	Cooled in air from 650°C. (1202°F.).....	5.335	38.5	"
31		4.489	32.4	"
32	Cooled in air from 700°C. (1292°F.).....	5.886	42.5	"
32		5.226	37.7	"
33	Cooled in air from 750°C. (1382°F.).....	5.663	40.8	"
33		4.801	34.7	"
34	Cooled in air from 800°C. (1472°F.).....	3.315	23.9	Mottled
34		3.223	23.2	"
35	Cooled in air from 850°C. (1562°F.).....	1.864	13.4	White metal-
35		1.864	13.4	lie luster

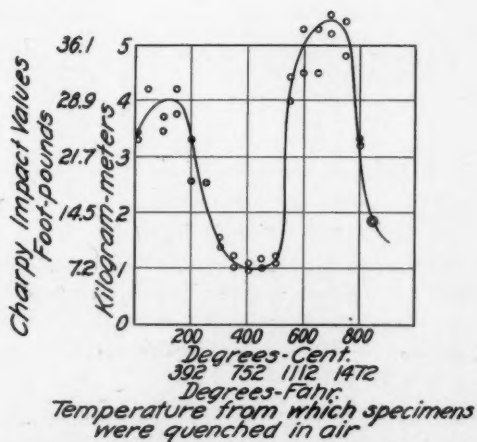


FIG. 5.—SHOWING A RELATION BETWEEN TEMPERATURE AND IMPACT VALUE FOR MALLEABLE SPECIMENS COOLED IN AIR FROM VARIOUS TEMPERATURES.

9. From these results we can see that the dangerous range, for embrittlement resulting from the heat treatment, lies between 250 degs. Cent. (482 degs. Fahr.) and 550 degs. Cent. (1022 degs. Fahr.) It also is evident that well-annealed malleable iron is converted by galvanizing to a brittle material having a white fracture (Fig. 6) with a metallic luster.

10. When the castings are cooled in water from 800 degs. Cent. (1472 degs. Fahr.), the material becomes very brittle due to reabsorption of temper carbon at the high temperature, forming austenite which is converted to martensite during the quick cooling. The results almost coincide with those obtained by Marshall.

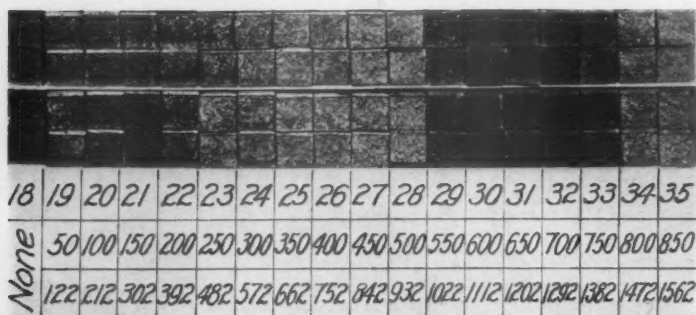


FIG. 6—SHOWING FRACTURES OF SPECIMENS COOLED IN AIR AFTER HEATING TO TEMPERATURES NOTED. SPECIMEN NOS. OF BARS SHOWN ARE GIVEN IN TOP ROW OF FIGURES. TEMPERATURES ARE SHOWN IN SECOND ROW (IN DEGS. CENT.) AND THIRD ROW (IN DEGS. FAHR.).

II—A Relation Between Temperature and Impact Value for Specimens Cooled in Air from Various Temperatures.

11. In this case, the specimens were cooled in air instead of in water after having been held for 20 minutes at different high temperatures. The results obtained are tabulated in Table 2 and shown graphically in Fig. 5, and the fractures of the specimens tested are to be seen in Fig. 6.

12. The above results show that when castings are cooled in air, from the dangerous range, embrittlement of the material results although to a lesser degree than in the case of water cooling.

Table 3

No. of Specimen	Heat Treatment*	Charpy Impact Values		Fracture
		Kg.-m.	Ft.-Lbs.	
36	100°C. (212°F.)	0.598	4.3	White
36		0.372	2.7	"
37	200°C. (392°F.)	0.753	5.4	"
37		0.361	2.6	"
38	300°C. (572°F.)	0.633	4.6	"
38		0.610	4.4	"
39	400°C. (752°F.)	0.620	4.5	"
39		0.574	4.2	"
40	450°C. (842°F.)	0.633	4.6	"
40		0.393	2.8	"
41	500°C. (932°F.)	1.059	7.6	"
41		1.032	7.4	"
42	600°C. (1112°F.)	2.548	18.4	Black
42		2.380	17.2	"
43	700°C. (1292°F.)	5.179	37.4	"
43		4.347	31.4	"

*All specimens cooled in water from 450 degs. Cent. (842 degs. Fahr.) after having been quenched in water from various temperatures, as tabulated.

III—Cooling Rates and Heat Treatment to Prevent Embrittlement of Malleable Cast Iron.

13. Although we obtain a good malleable cast iron as the result of careful annealing, the material may be embrittled if cooled in air or water from the temperature of the dangerous range, as in galvanizing. In an effort to find a method for preventing this embrittlement, the writer made further studies along the following lines:

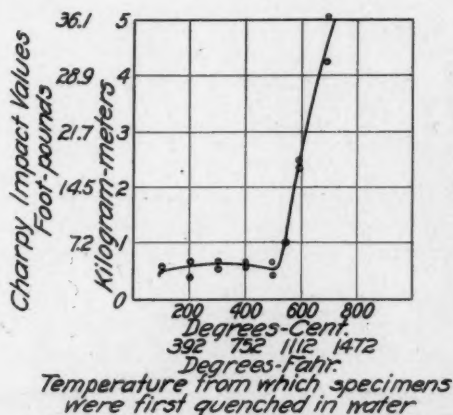


FIG. 7.—SHOWING EFFECT OF PREVIOUS WATER QUENCHING FROM VARIOUS TEMPERATURES ON IMPACT VALUE AFTER QUENCHING IN WATER FROM 450 DEGS. CENT. (842 DEGS. FAHR.)

Table 4

No. of Specimen	Heat Treatment*	Charpy Impact Values		Fracture
		Kg.-m.	Ft.-Lbs.	
44	500°C. (932°F.)	0.693	5.0	White
44		1.276	9.2	"
45	550°C. (1022°F.)	0.942	6.8	"
45		1.031	7.4	"
46	600°C. (1112°F.)	3.076	22.2	Black
46		3.541	25.6	"
47	650°C. (1202°F.)	3.790	27.4	"
47		4.759	34.3	"

*All specimens quenched in water from 450 degs. Cent. (842 degs. Fahr.), then cooled in water from various temperatures, as tabulated.

A. Black-Heart Malleable Cast Iron, Previously Water Quenched from Various Temperatures, Cooled in Water from 450 Degs. Cent. (842 Degs. Fahr.)

14. When malleable cast iron is quenched in water from 450 degs. Cent. (842 degs. Fahr.), embrittlement usually results. Experiments were made with several prior heat treatments to avoid this effect. Well-annealed malleable iron castings were first quenched in water from a series of increasing temperatures, after which they were reheated to 450 degs. Cent. (842 degs. Fahr.), quenched in water and impact values obtained. The results are tabulated in Table 3 and shown graphically in Fig. 7.

15. The curve in Fig. 7 shows that malleable cast iron, first

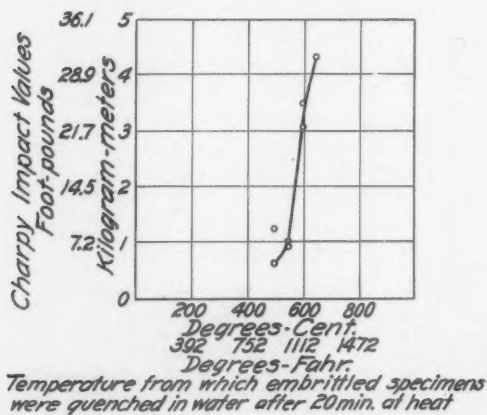


FIG. 8—IMPACT VALUE OF EMBRITTLED SPECIMENS AFTER QUENCHING IN WATER FROM VARIOUS TEMPERATURES ABOVE 450 DEGS. CENT. (842 DEGS. FAHR.)

cooled in water from temperatures below 550 degs. Cent. (1022 degs. Fahr.) is embrittled, as was the case when there was no preliminary heat treatment, when quenched in water from 450 degs. Cent. (842 degs. Fahr.) However, the material quenched in water from temperatures between 600 and 700 degs. Cent. (1112 and 1292 degs. Fahr.) does not become embrittled when exposed to a similar thermal treatment, as in the case of galvanizing.

16. The writer repeated the experiment and obtained exactly the same results, thus confirming the above.

B. Heat Treatment to Eliminate the Embrittlement of Malleable Cast Iron Which May Result from a Thermal Treatment Like Hot-Dip Galvanizing.

17. The well-annealed malleable iron castings which were quenched in water from 450 degs. Cent. (842 degs. Fahr.) and embrittled were reheated to various high temperatures above 450 degs. Cent., held for 20 minutes at the temperature, and then quenched in water. Impact tests were made on the specimens, the results of which are tabulated in Table 4 and shown graphically in Fig. 8.

18. These data show that galvanizing embrittlement can be corrected easily by quenching in water from 600 degs. Cent. (1112 degs. Fahr.) to 700 degs. Cent. (1292 degs. Fahr.)

C. To Determine Whether Malleable Iron Which Has Been Quenched from 650 Degs. Cent. (1202 Degs. Fahr.) Becomes Embrittled After Long Time Exposure in the Dangerous Temperature Range.

19. The results given in Table 5 show no impairment in impact values as a result of 5 to 10 hours exposure at 450 degs. Cent. (842 degs. Fahr.) to 500 degs. Cent. (932 degs. Fahr.)

IV—Effect of Cooling Rate, from a Temperature Below the A_{r1} Transformation Point, on Embrittlement of Malleable Cast Iron.

20. In the foregoing results we have seen the relation between temperatures of the heat treatment and the embrittlement of malleable cast iron. In practice, the castings are not always cooled so quickly as in the above cases. Therefore, it is very

Table 5

No. of Specimen	Heat Treatment*	Charpy Impact Values		Fracture
		Kg.m.	Ft.-Lbs.	
55	Held for 5 hours at 500°C. (932°F.)	4.801	34.7	Black
55		4.801	34.7	"
56	Held for 10 hours at 500°C. (932°F.)	4.592	33.2	"
56		4.065	29.5	"
57	Held for 5 hours at 450°C. (842°F.)	3.996	28.8	"
57		3.888	28.1	"
58	Held for 10 hours at 450°C. (842°F.)	4.185	30.2	"
58		4.695	34.0	"

*All specimens quenched in water from 650 degs. Cent. (1202 degs. Fahr.), reheated to and held at the temperatures indicated for the stated time interval, and then cooled in air.

Table 6

No. of Specimen	Heat Treatment*	Charpy Impact Value		Fracture
		Kg.m.	Ft.-Lbs.	
59	Cooling in air from 650°C. (1202°F.) to 450°C. (842°F.)	4.740	34.3	Black
59		4.801	34.7	"
60	30 min. cooling in furnace from 650°C. (1202°F.) to 100°C. (212°F.)	3.750	27.1	"
60		3.690	26.7	"
61	2 hrs. cooling in furnace from 650°C. (1202°F.) to 100°C. (212°F.)	3.846	27.8	"
61		3.986	28.8	"
62	4 hrs. cooling in furnace from 650°C. (1202°F.) to 100°C. (212°F.)	2.500	18.1	Mottled
62		3.223	23.3	"
63	6 hrs. cooling in furnace from 650°C. (1202°F.) to 100°C. (212°F.)	1.563	11.3	White
63		1.276	9.2	"
64	8 hrs. cooling in furnace from 650°C. (1202°F.) to 100°C. (212°F.)	1.666	12.0	"
64		1.417	10.2	"
65	10 hrs. cooling in furnace from 650°C. (1202°F.) to 100°C. (212°F.)	1.139	8.2	"
65		1.347	9.7	"
66	12 hrs. cooling in furnace from 650°C. (1202°F.) to 100°C. (212°F.)	1.276	9.2	"
66		1.276	9.2	"

*All specimens quenched in water after the various heat treatments tabulated, quenching taking place at lower temperatures shown.

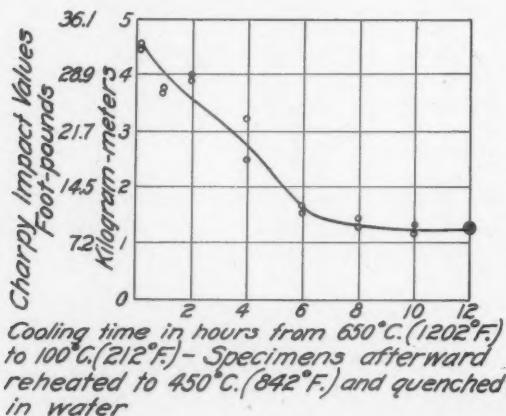


FIG. 9—SHOWING IMPACT VALUE OF SPECIMENS QUENCHED IN WATER FROM 450 DEGS. CENT. (842 DEGS. FAHR.) AFTER HAVING BEEN COOLED AT VARIOUS RATES FROM 650 DEGS. CENT. (1202 DEGS. FAHR.)

Table 7

No. of Specimen	Heat Treatment*	Charpy Impact Values		Fracture
		Kg.m.	Ft.-Lbs.	
67	Immediately.....	1.139	8.2	White
67		1.417	10.2	"
68	1 hour.....	1.139	8.2	"
68		1.336	11.8	"
69	2 hours.....	1.346	9.7	"
69		1.636	11.8	"
70	4 hours.....	1.711	12.3	Mottled
70		2.021	14.6	"
71	6 hours.....	1.785	12.9	"
71		1.785	12.9	"
72	8 hours.....	2.021	14.6	"
72		2.021	14.6	"
73	10 hours.....	1.787	12.9	"
73		2.264	16.3	"
74	12 hours.....	1.864	13.4	"
74		2.346	16.9	"

*All specimens held at 450 degs. Cent. (842 degs. Fahr.) for 20 minutes, then cooled in furnace to 100 degs. Cent. (212 degs. Fahr.) in the time stated.

important to study the degree of embrittlement suffered when the castings are cooled at different cooling rates from various temperatures.

21. *First Study:* After malleable-iron castings had been cooled at various cooling rates from 650 degs. Cent. (1202 degs. Fahr.), they were reheated to 450 degs. Cent. (842 degs. Fahr.) and cooled quickly in water. Impact values for the various conditions are tabulated in Table 6 and shown graphically in Fig. 9.

22. From these results we see that the material becomes completely brittle after quenching from 450 degs. Cent. (842 degs.

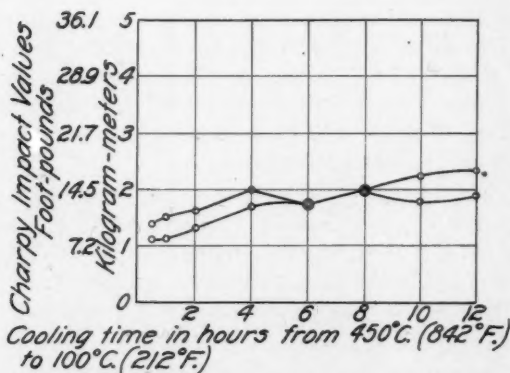


FIG. 10—SHOWING IMPACT VALUES OF SPECIMENS COOLED AT VARIOUS RATES FROM 450 DEGS. CENT. (842 DEGS. FAHR.) TO 100 DEGS. CENT. (212 DEGS. FAHR.)

Fahr.) when the previous cooling from 650 degs. Cent. (1202 degs. Fahr.) to 100 degs. Cent. (212 degs. Fahr.) consumes more than 4 hours. A quick cooling of the malleable-iron castings from a temperature between 650 degs. Cent. (1202 degs. Fahr.) and the Ar_1 point gives a very favorable result, as previously mentioned.

23. *Second Study:* If well-annealed malleable iron castings are heated to 450 degs. Cent. (842 degs. Fahr.) and quenched in water, they are embrittled. However, if they are very slowly cooled to room temperature, as in ordinary annealing with packing materials, they do not suffer any bad effect and are sufficiently ductile. It is not unreasonable, therefore, to assume that there is a critical cooling rate from 450 degs. Cent. (842 degs. Fahr.) which causes the material to be embrittled.

24. Specimens were heated to 450 degs. Cent. (842 degs. Fahr.), held for 20 minutes and then cooled at various rates to 100 degs. Cent. (212 degs. Fahr.), after which impact tests were made at room temperature. The results are tabulated in Table 7 and shown graphically in Fig. 10.

25. From these data it is evident that, to obtain ductile malleable cast iron, it is important to cool the material very slowly to a temperature above 200 degs. Cent. (392 degs. Fahr.) Unless the cooling is at the rate of 30 degs. Cent. (54 degs. Fahr.)* per hour, there is a possibility that the material will become comparatively brittle.

26. An example of this is the practice at malleable foundries where malleable-iron castings sometimes become embrittled by the comparatively quick cooling in air (as a result of removing the annealing pots from the furnace in the dangerous range of temperature), even though cooled very slowly to that temperature. Such castings, however, will show a proper microstructure, with the iron carbide well graphitized.

27. *Third Study:* Specimens were heated to 650 degs. Cent. (1202 degs. Fahr.), then cooled at various rates to 450 degs. Cent. (842 degs. Fahr.), from which temperature they were cooled (a) in water, (b) in air and (c) in furnace. Impact tests were made at room temperature and results obtained as shown in Table 8 and, graphically, in Fig. 11.

28. The cooling from 650 degs. Cent. (1202 degs. Fahr.) to 450 degs. Cent. (842 degs. Fahr.) must be at a rate greater than

* 30 Centigrade degrees are equal to 54 Fahrenheit degrees.

100 degs. Cent. (180 degs. Fahr.)* per hour in order to afford protection against embrittlement in the case of material quenched in water from 450 degs. Cent. (842 degs. Fahr.). When cooling in air or in the furnace from 450 degrees, the cooling rate from 650 degs. Cent. (1202 degs. Fahr.) is not so important.

* NOTE: This is not 212 degs. Fahr., since 100 Centigrade degrees are equal to 180 Fahrenheit degrees.

Table 8

No. of Specimen	Heat Treatment*	Charpy Impact Values Kg.m.	Ft.-Lbs.	Fracture
QUENCHED IN WATER				
80	Immediately, in furnace.....	4.085	29.5	Black
80		4.906	35.4	"
81	30 minutes.....	4.085	29.5	"
81		4.502	33.2	"
82	1 hour.....	4.592	33.2	"
82		4.696	33.9	"
83	2 hours.....	3.503	25.3	"
83		3.798	27.5	"
84	4 hours.....	2.021	14.6	Mottled
84		2.101	15.2	"
85	6 hours.....	1.207	8.7	White
85		1.276	9.2	"
COOLED IN AIR				
86	Immediately, in furnace.....	4.696	33.9	Black
86		5.663	40.9	"
87	30 minutes.....	4.696	33.9	"
87		5.226	37.8	"
88	1 hour.....	5.443	39.3	"
88		5.553	40.1	"
89	2 hours.....	4.488	32.4	"
89		5.119	37.0	"
90	4 hours.....	5.443	39.3	"
90		5.553	40.1	"
91	6 hours.....	4.185	30.2	"
91		4.592	33.2	"
COOLED IN FURNACE				
92	Immediately, in furnace.....	4.387	31.7	Black
92		5.012	36.2	"
93	30 minutes.....	4.488	32.4	"
93		5.663	40.8	"
94	1 hour.....	4.592	33.2	"
94		5.553	40.1	"
95	2 hours.....	3.986	28.8	"
95		5.012	36.2	"
96	4 hours.....	4.488	32.4	"
96		5.119	37.0	"
97	6 hours.....	4.387	31.7	"
97		5.012	36.2	"

*Specimens 80-85 quenched in water, specimens 86-91 cooled in air, and specimens 92-97 cooled in furnace, all from 450 degs. Cent. (842 degs. Fahr.) after cooling from 650 degs. Cent. (1202 degs. Fahr.) in the time stated.

RELATION BETWEEN TEMPERATURES AT WHICH COOLING
OF THE CASTING BEGINS, AFTER COMPLETION OF
THE GRAPHITIZATION, AND THE EMBRITTLEMENT
OBTAINED IN MALLEABLE CAST IRON

29. Graphitization having been completed, castings (as shown in Fig. 1) were removed from the annealing furnace at different points during the cooling cycle (as shown in Fig. 12) and cooled in air. Specimens were prepared from these annealed castings and

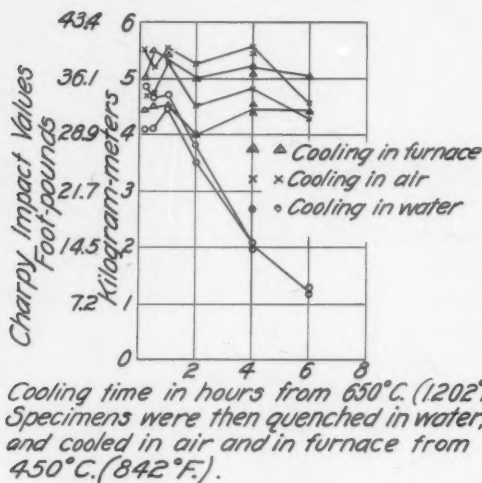


FIG. 11—SHOWING IMPACT VALUES OF SPECIMENS COOLED AT VARIOUS RATES FROM 650 DEGS. CENT. (1202 DEGS. FAHR.) TO 450 DEGS. CENT. (842 DEGS. FAHR.) FROM WHICH TEMPERATURES THEY WERE FURNACE, AIR AND WATER COOLED TO ROOM TEMPERATURE.

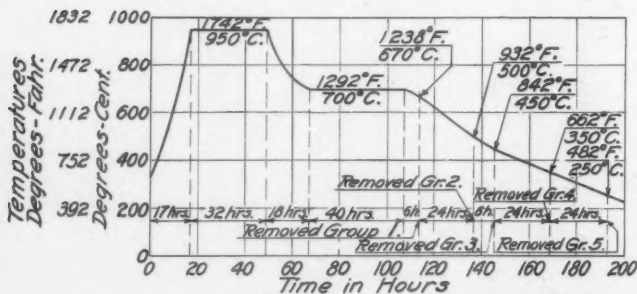


FIG. 12—SHOWING POINTS AT WHICH GROUPS OF SPECIMENS WERE REMOVED FROM ANNEAL AFTER COMPLETION OF GRAPHITIZATION.

Table 9

No. of Specimen	Heat Treatment	Charpy Impact Values		Fracture
		Kg.-m.	Ft.-Lbs.	
101	No heat treatment.....	4.286	31.0	Black
101		4.387	31.7	"
102	Cooled in air from 100°C. (212°F.).....	3.790	27.5	"
102		3.790	27.5	"
103	Cooled in air from 200°C. (392°F.).....	3.888	28.0	"
103		3.986	28.8	"
104	Cooled in air from 300°C. (572°F.).....	4.185	30.2	"
104		4.185	30.2	"
105	Cooled in air from 400°C. (752°F.).....	4.185	30.2	"
105		4.185	30.2	"
106	Cooled in air from 500°C. (932°F.).....	3.694	26.7	"
106		4.185	30.2	"
107	Cooled in air from 600°C. (1112°F.).....	3.986	28.8	"
107		4.592	33.2	"
108	Cooled in air from 700°C. (1292°F.).....	4.387	31.7	"
108		4.592	33.2	"
109	Cooled in air from 750°C. (1382°F.).....	3.790	27.5	"
109		4.185	30.2	"
110	Cooled in air from 800°C. (1472°F.).....	3.131	22.6	"
110		3.986	28.8	"
111	Cooled in water from 100°C. (212°F.).....	3.790	27.5	"
111		3.790	27.5	"
112	Cooled in water from 200°C. (392°F.).....	3.888	28.0	"
112		3.986	28.8	"
113	Cooled in water from 300°C. (572°F.).....	4.185	30.2	"
113		4.185	30.2	"
114	Cooled in water from 400°C. (752°F.).....	4.185	30.2	"
114		4.387	31.7	"
115	Cooled in water from 500°C. (932°F.).....	4.387	31.7	"
115		5.012	36.2	"
116	Cooled in water from 600°C. (1112°F.).....	4.185	30.2	"
116		4.185	30.2	"
117	Cooled in water from 700°C. (1292°F.).....	3.790	27.5	"
117		4.185	30.2	"
118	Cooled in water from 750°C. (1382°F.).....	3.790	27.5	"
118		4.286	31.0	"
119	Cooled in water from 800°C. (1472°F.).....	1.417	10.2	White
119		1.417	10.2	"

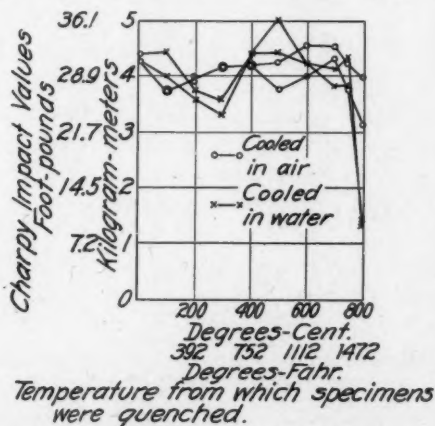


FIG. 13—SHOWING IMPACT VALUES OF SPECIMENS IN Group 1 WHICH WERE REMOVED FROM ANNEAL AT 670 DEGS. CENT. (1238 DEGS. FAHR.), COOLED IN AIR, AND FINALLY COOLED IN AIR AND WATER FROM VARIOUS TEMPERATURES.

Table 10

No. of Specimen	Heat Treatment	Charpy Impact Values		Fracture
		Kg.m.	Ft.-Lbs.	
120	No heat treatment.....	3.694	26.7	Black
120		4.185	30.2	"
121	Cooled in air from 100°C. (212°F.).....	3.503	25.3	"
122	Cooled in air from 200°C. (392°F.).....	3.986	28.8	"
123	Cooled in air from 300°C. (572°F.).....	4.185	30.2	"
124	Cooled in air from 350°C. (662°F.).....	3.598	26.0	"
125	Cooled in air from 400°C. (752°F.).....	3.790	27.4	"
126	Cooled in air from 450°C. (842°F.).....	3.888	28.0	"
126		3.223	23.3	"
127	Cooled in air from 500°C. (932°F.).....	3.082	22.3	"
128	Cooled in air from 550°C. (1022°F.).....	4.185	30.2	"
129	Cooled in air from 600°C. (1112°F.).....	4.592	33.2	"
130	Cooled in air from 650°C. (1202°F.).....	3.888	28.0	"
131	Cooled in water from 100°C. (212°F.).....	3.986	28.8	"
132	Cooled in water from 200°C. (392°F.).....	3.986	28.8	"
133	Cooled in water from 300°C. (572°F.).....	3.408	24.7	"
134	Cooled in water from 350°C. (662°F.).....	2.951	21.3	Mottled
135	Cooled in water from 400°C. (752°F.).....	1.942	14.0	"
136	Cooled in water from 450°C. (842°F.).....	1.417	10.2	White
137	Cooled in water from 500°C. (932°F.).....	1.006	7.2	"
137		0.942	6.8	"
138	Cooled in water from 550°C. (1022°F.).....	1.417	10.2	"
139	Cooled in water from 600°C. (1112°F.).....	3.888	28.0	Black
140	Cooled in water from 650°C. (1202°F.).....	4.594	33.2	"

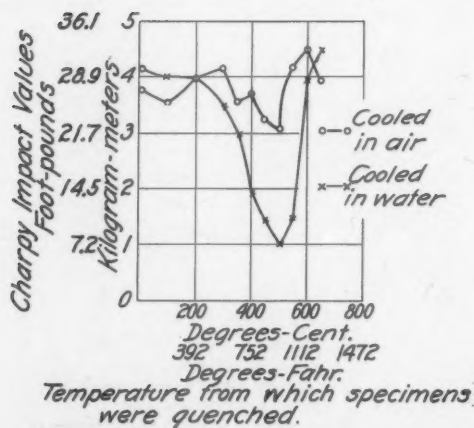


FIG. 14—SHOWING IMPACT VALUES OF THE SPECIMENS IN Group 2 WHICH WERE REMOVED FROM ANNEAL AT 500 DEGS. CENT. (932 DEGS. FAHR.), COOLED IN AIR, AND FINALLY COOLED IN AIR AND WATER FROM VARIOUS TEMPERATURES.

reheated to various temperatures, followed by air cooling and water quenching. Impact tests were made at room temperature.

30. *Group 1*—Castings removed from the annealing furnace at 670 degs. Cent. (1238 degs. Fahr.) and cooled in air: Specimens were reheated to various temperatures and cooled in air and water. The resulting impact values are tabulated in Table 9 and shown graphically in Fig. 13.

31. From these results it is seen that castings removed from the anneal at 670 degs. Cent. (1238 degs. Fahr.) and cooled in air are superior materials which will not become embrittled even though they are quenched in water from the temperature of the dangerous range. This treatment has the advantage of reduced annealing time, as compared with the ordinary annealing method where the cooling is at slower rates from the A_1 transformation point to the temperature at which the castings may be handled.

32. *Group 2*—Castings removed from the annealing furnace at 500 degs. Cent. (932 degs. Fahr.) and cooled in air: Specimens were reheated to various temperatures and cooled in air and water. The resulting impact values are shown in Table 10 and Fig. 14.

33. The malleable-iron castings removed from the annealing furnace at 500 degs. Cent. (932 degs. Fahr.) and cooled in air are not embrittled materially by cooling in air from the temperature of the dangerous range. However, if castings removed from the anneal as above and cooled in air are quenched from the dangerous range in water, the material becomes brittle. It will be noted that the dangerous range is not so wide as in the case of the ordinary malleable cast iron.

34. *Group 3*—Castings removed from the annealing furnace at 450 degs. Cent. (842 degs. Fahr.) and cooled in air: Specimens were reheated to various temperatures and cooled in air and water. The resulting impact values are tabulated in Table 11 and shown graphically in Fig. 15.

35. In this group the material suffered some slight embrittlement when air cooled, while the specimens which were quenched in water were embrittled. The dangerous range is wider in comparison with *Group 2*. This is a very interesting result and explains some of the hitherto unaccounted-for facts of actual practice in the foundry.

36. *Group 4*—Castings removed from the annealing furnace at 350 degs. Cent. (662 degs. Fahr.) and cooled in air: Specimens

Table 11

No. of Specimen	Heat Treatment	Charpy Impact Values		Fracture
		Kg.m.	Ft.-Lbs.	
141	No heat treatment.....	3.790	27.4	Black
141		3.888	28.0	"
142	Cooled in air from 100°C. (212°F.).....	3.598	26.0	"
143	Cooled in air from 200°C. (392°F.).....	3.598	26.0	"
144	Cooled in air from 250°C. (482°F.).....	3.314	23.9	"
145	Cooled in air from 300°C. (572°F.).....	3.223	23.3	"
145		3.314	23.9	"
146	Cooled in air from 350°C. (662°F.).....	2.182	15.8	Mottled
146		3.408	24.7	"
147	Cooled in air from 400°C. (752°F.).....	2.686	19.4	"
147		3.223	23.3	"
148	Cooled in air from 450°C. (842°F.).....	2.343	16.9	"
148		2.686	19.4	"
149	Cooled in air from 500°C. (932°F.).....	3.223	23.3	"
149		3.408	24.7	"
150	Cooled in air from 550°C. (1022°F.).....	3.887	28.0	Black
150		4.284	31.0	"
151	Cooled in air from 600°C. (1112°F.).....	4.592	33.2	"
152	Cooled in air from 650°C. (1202°F.).....	4.801	34.7	"
153	Cooled in water from 100°C. (212°F.).....	3.442	24.9	"
154	Cooled in water from 200°C. (392°F.).....	2.950	21.3	"
155	Cooled in water from 250°C. (482°F.).....	3.130	22.6	"
156	Cooled in water from 300°C. (572°F.).....	2.514	18.1	Mottled
156		2.514	18.1	"
157	Cooled in water from 350°C. (662°F.).....	1.563	11.3	"
157		1.864	13.5	"
158	Cooled in water from 400°C. (752°F.).....	1.139	8.2	White
158		1.206	8.7	"
159	Cooled in water from 450°C. (842°F.).....	0.878	6.3	"
159		0.878	6.3	"
160	Cooled in water from 500°C. (932°F.).....	1.006	7.2	"
160		0.878	6.3	"
161	Cooled in water from 550°C. (1022°F.).....	1.417	10.2	"
161		1.417	10.2	"
162	Cooled in water from 600°C. (1112°F.).....	3.598	26.0	Black
163	Cooled in water from 650°C. (1202°F.).....	4.282	31.0	"

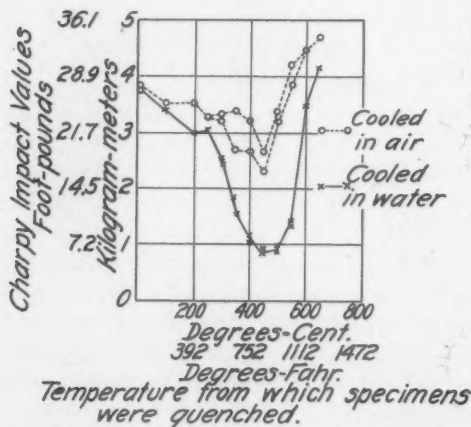


FIG. 15—SHOWING IMPACT VALUES OF SPECIMENS IN Group 3 WHICH WERE REMOVED FROM ANNEAL AT 450 DEGS. CENT. (842 DEGS. FAHR.), COOLED IN AIR, AND FINALLY COOLED IN AIR AND WATER FROM VARIOUS TEMPERATURES.

Table 12

No. of Specimen	Heat Treatment	Charpy Impact Values		Fracture
		Kg.m.	Ft.-Lbs.	
164	No heat treatment.....	1.943	14.0	Mottled
164		1.943	14.0	"
165	Cooled in air from 100°C. (212°F.).....	1.864	13.5	White
166	Cooled in air from 200°C. (392°F.).....	1.563	11.3	"
167	Cooled in air from 300°C. (572°F.).....	1.417	10.2	"
167		1.139	8.2	"
168	Cooled in air from 350°C. (662°F.).....	1.003	7.2	"
168		1.276	9.2	"
170	Cooled in air from 400°C. (752°F.).....	0.814	5.9	"
170		0.878	6.3	"
171	Cooled in air from 450°C. (842°F.).....	1.006	7.2	"
171		1.070	7.7	"
172	Cooled in air from 500°C. (932°F.).....	1.471	10.6	"
172		2.514	18.2	"
173	Cooled in air from 550°C. (1022°F.).....	2.686	19.4	Black
173		3.790	27.4	"
174	Cooled in air from 600°C. (1112°F.).....	3.925	28.3	"
175	Cooled in air from 650°C. (1202°F.).....	4.185	30.2	"
176	Cooled in water from 100°C. (212°F.).....	1.638	11.8	White
177	Cooled in water from 200°C. (392°F.).....	1.864	13.5	"
178	Cooled in water from 250°C. (482°F.).....	1.276	9.2	"
179	Cooled in water from 300°C. (572°F.).....	1.139	8.2	"
179		1.139	8.2	"
180	Cooled in water from 350°C. (662°F.).....	0.878	6.3	"
180		0.940	6.8	"
181	Cooled in water from 400°C. (752°F.).....	0.753	5.4	"
181		0.814	5.9	"
182	Cooled in water from 450°C. (842°F.).....	0.633	4.6	"
182		0.693	5.0	"
183	Cooled in water from 500°C. (932°F.).....	0.693	5.0	"
183		0.878	6.3	"
184	Cooled in water from 550°C. (1022°F.).....	1.207	8.7	"
184		1.276	9.2	"
185	Cooled in water from 600°C. (1112°F.).....	2.861	20.7	Black
185		3.040	22.0	"
186	Cooled in water from 650°C. (1202°F.).....	4.085	29.5	"

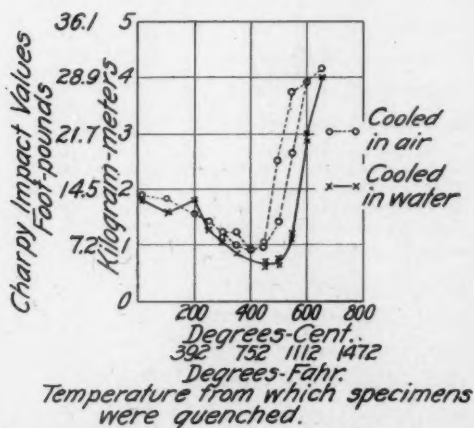


FIG. 16—SHOWING IMPACT VALUES OF SPECIMENS IN Group 4 WHICH WERE REMOVED FROM ANNEAL AT 350 DEGS. CENT. (662 DEGS. FAHR.), COOLED IN AIR, AND FINALLY COOLED IN AIR AND WATER FROM VARIOUS TEMPERATURES.

were reheated to various temperatures and cooled in air and water. The resulting impact values are shown in Table 12 and Fig. 16.

37. In the case of *Group 4* the castings are somewhat brittle, as shown by the impact values, and the fracture shows a white metallic luster even before heat treatment. This brittleness, however, is not due to an incomplete graphitization of white cast iron. In practice, we have sometimes experienced the same kind of phenomenon. If such brittle castings are obtained in practice, the brittleness may be removed merely by quenching in air or water from 650 degs. Cent. (1202 degs. Fahr.)

38. *Group 5*—Castings removed from the annealing furnace at 250 degs. Cent. (482 degs. Fahr.) and cooled in air: Specimens were reheated to various temperatures and cooled in air and water. The resulting impact values are shown in Table 13 and Fig. 17.

39. In the case of *Group 5* the impact value of untreated

Table 13

No. of Specimen	Heat Treatment	Charpy Impact Values		Fracture
		Kg.m.	Ft.-Lbs.	
187	No heat treatment.....	1.864	13.5	Mottled
187		2.430	17.5	"
188	Cooled in air from 100°C. (212°F.).....	2.430	17.5	"
189	Cooled in air from 200°C. (392°F.).....	1.182	8.5	"
190	Cooled in air from 250°C. (482°F.).....	2.346	16.9	"
191	Cooled in air from 300°C. (572°F.).....	1.417	10.2	White
191		1.943	14.0	"
192	Cooled in air from 350°C. (662°F.).....	1.206	8.7	"
192		1.490	10.8	"
193	Cooled in air from 400°C. (752°F.).....	0.914	6.6	"
193		1.276	9.2	"
194	Cooled in air from 450°C. (842°F.).....	1.139	8.3	"
194		1.276	9.2	"
195	Cooled in air from 500°C. (932°F.).....	1.346	9.7	"
195		2.686	19.4	Mottled
196	Cooled in air from 550°C. (1022°F.).....	3.986	28.8	Black
196		3.986	28.8	"
197	Cooled in air from 600°C. (1112°F.).....	3.095	22.3	"
198	Cooled in air from 650°C. (1202°F.).....	3.897	28.1	"
199	Cooled in water from 100°C. (212°F.).....	2.950	21.3	Mottled
200	Cooled in water from 200°C. (392°F.).....	2.182	15.7	"
201	Cooled in water from 250°C. (482°F.).....	2.346	16.9	"
202	Cooled in water from 300°C. (572°F.).....	1.417	10.2	White
202		1.711	12.3	"
203	Cooled in water from 350°C. (662°F.).....	0.878	6.3	"
203		0.940	6.8	"
204	Cooled in water from 400°C. (752°F.).....	0.576	4.1	"
204		0.756	5.5	"
205	Cooled in water from 450°C. (842°F.).....	0.653	4.7	"
205		0.815	5.9	"
206	Cooled in water from 500°C. (932°F.).....	0.815	5.9	"
206		0.815	5.9	"
207	Cooled in water from 550°C. (1022°F.).....	2.186	15.8	Mottled
207		2.686	19.4	"
208	Cooled in water from 600°C. (1112°F.).....	4.185	30.2	Black
208		4.592	33.2	"
209	Cooled in water from 650°C. (1202°F.).....	2.861	20.7	"

material is greater than it was in *Group 4* but the material is embrittled by a heat treatment similar to galvanizing, as was the ordinary malleable cast iron (Fig. 4). Hence, if, as in the case where packing materials are used, the castings cannot be quickly cooled from a temperature ranging from 650 to 700 degs. Cent. (1202 to 1292 degs. Fahr.)—or the Ar_1 point—they must be cooled to a temperature below 200 degs. Cent. (392 degs. Fahr.) before being removed from the furnace.

40. From the results obtained (paragraphs 29-39), it is evident that to obtain superior malleable cast iron, castings must be cooled quickly from a temperature between 650 degs. Cent. (1202 degs. Fahr.) and the Ar_1 point, after completing the graphitization (both stages). In view of this it is preferable to use an electric annealing furnace for the purpose of manufacturing high-grade malleable-iron castings.

41. When we use a large coal- or oil-fired annealing furnace, with packing material, we cannot cool very quickly from the temperature just below the Ar_1 point and must continue the cooling, therefore, to a temperature below 200 degs. Cent. (392 degs. Fahr.), after completing the graphitization, and increase the annealing time by so doing. If the brittle material is obtained notwithstanding a good annealing, the castings should be quenched from 650 degs. Cent. (1202 degs. Fahr.) before reannealing.

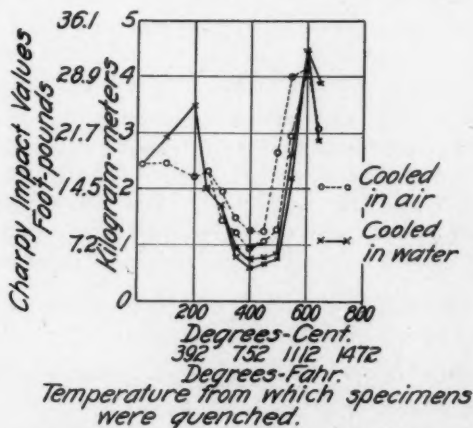


FIG. 17—SHOWING IMPACT VALUES OF SPECIMENS IN *Group 5* WHICH WERE REMOVED FROM ANNEAL AT 250 DEGS. CENT. (482 DEGS. FAHR.), COOLED IN AIR, AND FINALLY COOLED IN AIR AND WATER FROM VARIOUS TEMPERATURES.

IMPACT TEST AT VARIOUS TEMPERATURES

42. In preceding sections, many results of impact tests made at room temperature were given for malleable-iron specimens which had been thermally treated.

43. In the malleable iron foundry it may be necessary to straighten castings after annealing, as there is some degree of distortion at the high temperatures, due to the weight of the castings and dilation due to the graphitization of cementites in white iron. Small pieces may be straightened with a hammer, while the larger castings may require a hydraulic press.

44. With large pieces, the straightening should be done at slightly elevated temperatures in order to avoid breakage, and it is desirable to know what temperatures are most suitable. It also will be of practical value to know the impact values at temperatures below 0 degs. Cent. (32 degs. Fahr.)

45. Impact tests were made at temperatures from -190 to 900 degs. Cent. (-310 to 1652 degs. Fahr.) using the same Charpy impact machine mentioned in the preceding sections. Tests were made on specimens as annealed, and as annealed and heat treated.

46. For temperatures over 100 degs. Cent. (212 degs. Fahr.) a small electric furnace was used to heat the specimens, and a water bath was used for temperatures from 0 to 100 degs. Cent. (32 to 212 degs. Fahr.) For the low temperatures a mixture of ice and salt was used for the range 0 to -20 degs. Cent. (32 to -4 degs. Fahr.), and liquid air was used for the lowest temperature, -190 degs. Cent. (-310 degs. Fahr.)

47. The heating and cooling apparatus was located close to the impact testing machine so that the temperature of the specimen in the machine, or during the test, differed but slightly from that measured in the furnace or the bath. This difference was measured in order to determine the correction factor and thus permit recording of temperatures as "temperatures at time of testing."

*I—Black-Heart Malleable Cast Iron as Annealed
and Without Thermal Treatment.*

48. Impact values at various temperatures are tabulated in Table 14 and shown graphically in Fig. 18. The curve in Fig. 18 shows two maxima and one minimum for the impact value of malleable cast iron at various temperatures.

49. Similar to iron and steel, malleable cast iron becomes very

Table 14

No. of Specimen	Temperature at Time of Testing		Charpy Impact Values		Fracture
	Degs. Cent.	Degs. Fahr.	Kg.-m.	Ft.-lbs.	
210	-189	-308	0.297	2.1	White
210			0.297	2.1	"
211	-19	-2	1.006	7.2	"
211	-17	-1	1.267	9.1	"
212	0	32	2.346	16.9	Mottled
212			2.600	18.8	"
213	23	73	3.694	26.7	Black
213			4.085	29.5	"
214	61	142	4.906	35.4	"
214			5.226	37.8	"
215	99	210	4.185	30.2	"
215			4.728	34.2	"
216	148	298	4.592	33.2	"
216			5.012	36.2	"
217	132	270	4.185	30.2	"
217			5.225	37.8	"
218	198	388	4.185	30.2	"
218			4.286	30.9	"
219	297	567	2.861	20.7	
220	412	774	3.694	26.7	
220			3.986	28.8	
221	446	835	2.686	19.4	
221			3.790	27.4	
222	510	950	3.040	21.9	
222			3.332	24.1	
223	595	1103	2.686	19.4	
223			3.132	22.6	
224	690	1274	3.223	23.3	Not clear because of oxide film
224			3.694	26.7	
225	742	1368	4.592	33.2	
225			5.226	37.8	
226	790	1454	5.775	41.7	
226			6.338	45.7	
227	900	1652	4.592	33.2	
227			5.663	40.8	

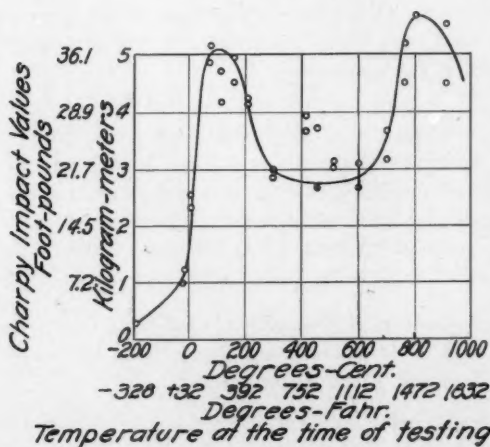


FIG. 18—IMPACT VALUES OF BLACK-HEART MALLEABLE CAST IRON, AS ANNEALED, AT VARIOUS TEMPERATURES.

brittle when it is cooled to a temperature below 0 degs. Cent. (32 degs. Fahr.) Malleable-iron castings are seen to develop a high resistance to impact in the temperature range, 50 to 200 degs. Cent. (122 to 392 degs. Fahr.), so that this range is a desirable one to employ when straightening castings distorted in the anneal.

50. The low impact value may be explained, as will be discussed later, as due to the special property of the carbide which deposits at the grain boundaries of the ferrite structure. The increment of the impact value with increasing temperature up to 700 degs. Cent. (1292 degs. Fahr.) is a characteristic property of the iron matrix, while the decrease in impact value, with increasing temperature above 800 degs. Cent. (1472 degs. Fahr.), is attributed to the absorption of temper carbon and conversion of the ferrite to austenite.

*II—Annealed Black-Heart Malleable Cast Iron
Quenched in Water from 450 Degs. Cent.
(842 Degs. Fahr.)—the Galvanizing Temperature.*

51. Impact values at various temperatures are tabulated in Table 15 and shown graphically in Fig. 19. It is seen that for malleable cast iron cooled quickly from 450 degs. Cent. (842 degs. Fahr.), as in galvanizing, the impact value curve (Fig. 19) is similar to that for ordinary annealed malleable (Fig. 18) except that the brittle range is wider. The form of the curve up to 300 degs. Cent. (572 degs. Fahr.) is similar to that of Fig. 18 and may be explained in the same way.

52. If a casting, which is brittle at room temperature, is heated to a temperature of 130 to 250 degs. Cent. (266 to 482 degs. Fahr.), it will become ductile and have almost the same impact value as a good malleable casting with a fracture having the black luster of good malleable. However, when cooled down to room temperature—about 20 degs. Cent. (68 degs. Fahr.)—the fracture will show a white metallic luster with accompanying brittleness.

*III—Annealed Black-Heart Malleable Cast Iron
Cooled Quickly in the Air from 650 Degs.
Cent. (1202 Degs. Fahr.)*

53. Impact values at various temperatures are tabulated in Table 16 and shown graphically in Fig. 20.

54. After heat treatment, i.e., quick cooling in air from

Table 15

No. of Specimen	Temperature at Time of Testing		Charpy Impact Values		Fracture
	Degs. Cent.	Degs. Fahr.	Kg.m.	Ft.-lbs.	
228	-186	-303	0.350	2.5	White
228			0.350	2.5	"
229			0.350	2.5	"
229			0.733	5.4	"
230	23	73	0.516	3.7	"
230			0.516	3.7	"
231	50	122	1.006	7.2	"
231			1.006	7.2	"
232	55	132	0.940	6.8	"
232			1.006	7.2	"
233	79	174	1.006	7.2	"
233			1.276	9.2	"
234	91	196	1.346	9.7	"
234			1.276	9.2	"
235	99	210	1.417	10.2	"
235			1.742	12.6	"
236	109	228	1.711	12.4	"
236			1.711	12.4	"
237	132	270	4.185	30.2	Black
237			4.387	31.7	"
238	148	298	4.592	33.2	"
238			4.592	33.2	"
239	198	358	4.801	34.7	"
239			5.119	37.0	"
240	297	567	3.006	21.7	"
240			3.986	28.8	"
241	411	772	3.540	25.6	"
241			3.540	25.6	"
242	448	838	2.950	21.3	Not clear because of oxide film
242			3.986	28.8	
243	510	950	3.130	22.6	
243			3.403	24.6	

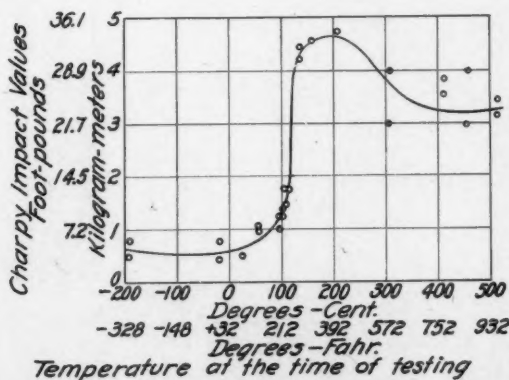


FIG. 19—IMPACT VALUES, AT VARIOUS TEMPERATURES OF ANNEALED MALLEABLE SPECIMENS QUENCHED IN WATER FROM 450 DEGS. CENT. (842 DEGS. FAHR.)

650 degs. Cent. (1202 degs. Fahr.), the impact value is high at all temperatures save the very low one obtained by liquid air. Thus, to obtain superior malleable cast iron, the annealing treatment should be followed by a quench, either in air or water, from a temperature approximating 650 degs. Cent. (1202 degs. Fahr.)

MICROSCOPIC OBSERVATION AND HARDNESS TESTS ON
MALLEABLE CAST IRON WHICH HAS BEEN THERMALLY
TREATED, AND MEASUREMENTS OF ELECTRICAL RE-
SISTANCE DURING BOTH HEATING AND COOLING

55. If there is a structural change in a material, it is generally accompanied by a change of physical properties. For instance, when a steel containing 0.9 per cent of carbon is heated to a temperature above the A_r transformation point and quenched, an increase in hardness and tensile strength is affected along with a reduction in ductility and impact value, while the structure is changed from pearlitic to martensitic. Malleable cast iron is embrittled by heating to 300 degs. Cent. (572 degs. Fahr.) to 550 degs. Cent. (1022 degs. Fahr.) and cooling quickly in air or water, and as this temperature range is far below the A_r point, we cannot consider any structural change.

Table 16

No. of Specimen	Temperature at Time of Testing		Charpy Impact Values		Fracture
	Degs. Cent.	Degs. Fahr.	Kg.m.	Ft.-lbs.	
244	-188	-306	0.815	5.9	White
244			0.938	6.8	"
245	-19	-2	3.598	26.0	Black
245			4.035	29.2	"
246	0	32	4.245	30.7	"
246			4.245	30.7	"
247	20	68	4.387	31.7	"
247			4.286	30.9	"
248	99	210	3.986	28.8	"
248			4.085	29.5	"
249	218	424	3.790	27.4	"
249			4.085	29.5	"
250	297	567	3.598	26.0	"
250			3.888	28.1	"
251	412	774	2.951	21.3	Not clear
251			3.508	25.4	"
252	446	835	2.951	21.3	"
252			3.040	22.0	"
253	510	950	2.861	20.7	"
253			3.040	22.0	"
254	595	1103	2.973	21.5	"
254			2.951	21.3	"
255	688	1270	3.040	22.0	"
255			3.132	22.6	"
256	790	1454	4.952	35.8	"
256			4.801	34.7	"

56. The writer attempted to formulate a theory of embrittlement through observing the microstructure, measuring the hardness at the room temperature, and by taking consideration of an electric property observed during the heating and cooling of malleable cast iron as annealed and as annealed and thermally treated. Maintaining the polishing and etching as nearly constant as possible, microscopic examination was made on specimens subjected to the following thermal treatment:

- (a) Slowly cooled after graphitization completed.
- (b) Slowly cooled after completion of graphitization, followed by quenching in water from 450 degs. Cent. (842 degs. Fahr.)

Table 17

No. of Specimen.	Heat Treatment.	Brinell Hardness.	Fracture.
1	None.....	105	Black
2	Cooled in water from 50°C. (122°F.).....	107	"
3	Cooled in water from 100°C. (212°F.).....	103	"
4	Cooled in water from 150°C. (302°F.).....	107	"
5	Cooled in water from 200°C. (392°F.).....	109	Mottled
6	Cooled in water from 250°C. (482°F.).....	107	White
7	Cooled in water from 300°C. (572°F.).....	116	"
8	Cooled in water from 350°C. (662°F.).....	106	"
9	Cooled in water from 400°C. (752°F.).....	116	"
10	Cooled in water from 450°C. (842°F.).....	107	"
11	Cooled in water from 500°C. (932°F.).....	107	"
12	Cooled in water from 550°C. (1022°F.).....	112	Black
13	Cooled in water from 600°C. (1112°F.).....	114	"
14	Cooled in water from 650°C. (1202°F.).....	110	"
15	Cooled in water from 700°C. (1292°F.).....	131	"
16	Cooled in water from 750°C. (1382°F.).....	166	"

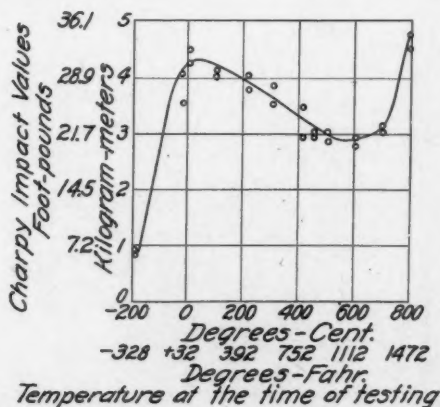


FIG. 20.—IMPACT VALUES, AT VARIOUS TEMPERATURES, OF ANNEALED MALLEABLE WHICH HAD BEEN AIR COOLED FROM 650 DEGS. CENT. (1202 DEGS. FAHR.)

(c) Slowly cooled after completion of graphitization, followed by quenching in water from 650 degs. Cent. (1202 degs. Fahr.)

57. No difference in microstructure could be detected at 100 diameters magnification, but at 1000 diameters some differences might be observed.

58. Brinell hardness numbers for annealed malleable-iron specimens, cooled in water from various temperatures, are shown in Table 17. In this table, no appreciable difference in hardness is observed except for a slight increase when the castings were cooled from the range of 700 to 750 degs. Cent. (1292 to 1382 degs. Fahr.) Therefore, there is no change in hardness due to the heat treatment in the dangerous range (300 to 550 degs. Cent., 572 to 1022 degs. Fahr.) even though the impact value is greatly impaired by such treatment.

59. Electrical resistance measurements were made by the potential drop method, during heating and cooling, of two series of malleable cast-iron specimens, one set being in the annealed condition while the other had been quenched in water from 650 degs. Cent. (1202 degs. Fahr.) after annealing. The specimens used were cylindrical rods, 5 mm. (0.197 in.) in diameter and 200 mm. (7.87 in.) in length.

60. The potential drop between two points 100 mm. (3.94 in.) apart was carefully measured by a potentiometer during the

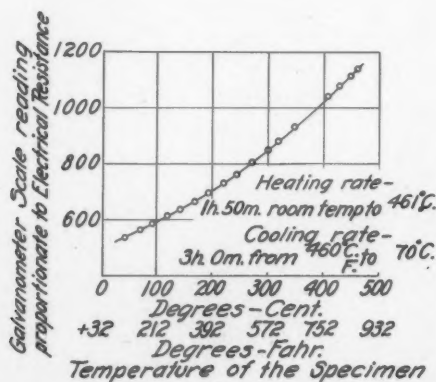


FIG. 21—ELECTRICAL RESISTANCE DURING HEATING AND COOLING OF AN ANNEALED MALLEABLE CAST IRON SPECIMEN.

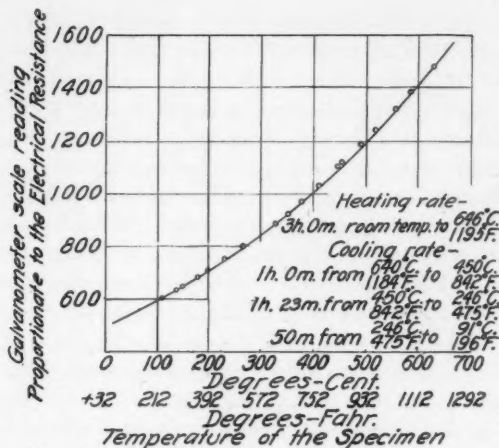


FIG. 22—ELECTRICAL RESISTANCE DURING HEATING AND COOLING OF AN ANNEALED MALLEABLE CAST IRON SPECIMEN WHICH HAD BEEN QUENCHED IN WATER FROM 650 DEGS. CENT. (1202 DEGS. FAHR.) AFTER ANNEALING.

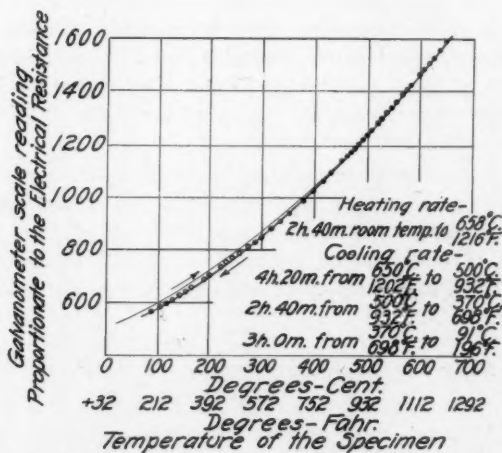


FIG. 23—ELECTRICAL RESISTANCE DURING HEATING AND COOLING OF AN ANNEALED MALLEABLE CAST IRON SPECIMEN WHICH HAD BEEN QUENCHED IN WATER FROM 650 DEGS. CENT. (1202 DEGS. FAHR.) AFTER ANNEALING. COOLING RATE WAS SLOWER THAN THAT IN FIG. 22.

flow of a current of 3 amperes. The temperature of the specimen was measured by a *Pt* and *Pt-Ro* thermocouple, which was inserted in a 2-mm. (0.157 in.) hole drilled in the middle of the specimen.

61. The results obtained are shown in Figs. 21 to 23, inclusive. The ordinate denotes the scale reading, proportional to the electric resistance, due to the deflection of the mirror in the galvanometer; and the abscissa denotes the temperature of the specimen. Fig. 21 shows the relation between the temperature of an annealed malleable specimen and its electric resistance up to 450 degs. Cent. (842 degs. Fahr.) The heating and cooling rates are dissimilar, but the heating curve coincides exactly with the cooling curve.

62. Figs. 22 and 23 show the same relation as Fig. 21, the specimens in this case having been quenched from 650 degs. Cent. (1202 degs. Fahr.) after annealing. While the heating rate was the same in both cases, the cooling rate was different in three stages. In the case of Fig. 22, the cooling and heating rates are nearly equal, and the heating and cooling curves coincide.

63. The cooling rate in Fig. 23 was much slower than the heating rate (also, the cooling rate was slower than that in Fig. 22), and the heating and cooling curves do not coincide.

64. Below 450 degs. Cent. (842 degs. Fahr.) the electrical resistance during cooling is less than the electrical resistance during heating. From this lack of coincidence the assumption is made that the electric resistance of malleable cast iron, quenched in water from 650 degs. Cent. (1202 degs. Fahr.) after annealing, is slightly greater than that of normally annealed malleable cast iron which has had no additional heat treatment.

65. Generally, when an alloy is a solid solution, its electrical resistance is greater than it would be if one of the constituents were precipitated from the solution. In view of this, the above decrement of the electrical resistance (Fig. 23) can be easily explained as due to separation of carbide at the grain boundaries of the ferrite.

A THEORY OF THE EMBRITTLEMENT OF MALLEABLE CAST IRON

66. Although some reports have been published, no theory has been advanced to explain the embrittlement of malleable cast iron. The phenomenon is similar to temper-brittleness³ in nickel-

³ K. Honda and R. Yamada, *Science Report No. 16*, p. 307, 1927; S. Malta, Publication of the World Engineering Congress, Tokio, 1929.

chromium steel, and since in both cases the brittleness is caused by very slow cooling from 650 degs. Cent. (1202 degs. Fahr.), a similar theory can be built up for the embrittlement of malleable cast iron, although some assumptions are introduced here.

67. The main point of the theory is that the carbide, present in malleable cast iron, separates from the ground metal and deposits at the grain boundaries of the ferrite, causing embrittlement. To make the matter clear, it is convenient to refer to the iron side of the iron-carbon diagram shown in Fig. 24, in which ordinates denote temperature, and abscissas, carbon concentration.

68. Line BD denotes the A_1 point, where austenite is changed to martensite and then into pearlite during the cooling, and the reverse action takes place during heating. Line BC illustrates the solubility of carbide in ferrite, and its inclination to the abscissa depends upon the chemical composition of the material. In slowly cooled malleable cast iron, carbide separates from the ferrite, which carries a small amount of carbide in solid solution, and is deposited at the ferrite grain boundaries.

69. From the experimental evidence presented in the foregoing, the following assumptions may be made regarding the carbide which is deposited at the ferrite grain boundaries:

- (a) The carbide is very brittle at room temperature after having been subjected to a quick cooling from a temperature range of 300 to 500 degs. Cent. (572 to 932 degs. Fahr.)

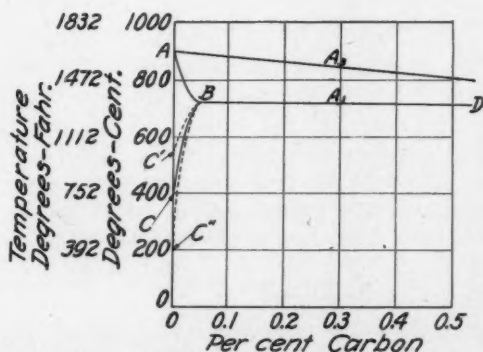


FIG. 24—IRON SIDE OF IRON-CARBON DIAGRAM. LINE BC ILLUSTRATES THE SOLUBILITY OF CARBIDE IN FERRITE.

(b) The carbide becomes less brittle at a temperature above 130 degs. Cent. (266 degs. Fahr.), even though previously brittle at room temperature following the quick cooling from the dangerous range.

(c) The carbide does not cause any brittleness at room temperature when a malleable casting is cooled very slowly to room temperature, after completing the graphitization.

70. If the carbide is deposited at the grain boundaries of the surface metal, a plane of weakness is present at that point and the effect is analogous to a notched specimen. Therefore, a malleable-iron casting which is cooled quickly in water or air from 450 degs. Cent. (842 degs. Fahr.) is very sensitive to impact or shock at room temperature, although the same casting at a temperature above 130 degs. Cent. (266 degs. Fahr.) has the impact resistance of the ordinary good malleable cast iron, which it loses when cooled back to room temperature.

71. When malleable cast iron is cooled quickly from a temperature above the line *BC*—for example, 650 degs. Cent. (1202 degs. Fahr.)—and afterwards is quickly cooled from the dangerous range, as in galvanizing, it is not brittle at ordinary temperature or even at lower temperatures down to -20 degs. Cent. (-4 degs. Fahr.)

72. Attention is directed to the following points: Generally, it requires some interval of time to complete a transformation, so that a transformation which takes place during heating is always at a higher temperature than that at which the same transformation takes place during cooling.

73. The magnitude of this temperature difference depends upon the rate of heating and cooling, as well as on the chemical composition of a material. For example, in ordinary high carbon steel, the A_{c1} transformation takes place at 750 degs. Cent. (1382 degs. Fahr.), while the A_{r1} point is at 700 degs. Cent. (1292 degs. Fahr.) Similarly, the temperature at which carbide separates from ferrite also is dependent on the rates of cooling and heating; i. e., in Fig. 24, line *BC* will take a position such as *BC'* in the heating and *BC''* in the cooling.

74. With the above facts and the results expounded in the preceding sections, the phenomena which accompany the heat treatment of malleable iron may be satisfactorily explained.

DISCUSSION

WRITTEN DISCUSSION

S. EPSTEIN* AND B. N. DANILOFF†: The author is to be commended for his precise determinations of the effects of the different heat treatment variables he has used on the impact properties of malleable cast iron. There now can be no doubt that quenching from about 650 degs. Cent. (1202 degs. Fahr.) produces immunity from embrittlement which otherwise would result on subsequent rapid cooling from 450 degs. Cent. (842 degs. Fahr.), the galvanizing temperature.

The described cause or mechanism of this effect attributed by the author to be due to solution followed by precipitation of iron carbide in the ferrite, is evidently a simplified, schematic representation rather than a conclusion based on experiment. Carbon certainly is not the only element present in malleable capable of producing dispersion hardening or embrittling effects. Nitrogen, oxygen, and phosphorus all can act in the same way, and the presence or absence of each of these elements no doubt would influence the behavior of the others. In this manner silicon also can play a part.

Since the author's hypothesis evidently is based on the recent proposed explanations of the blue-heat and embrittlement phenomena in mild steel, it is well to point out that there, too, the ideas on the subject are still in a very unsettled state.⁴ The facts in the case of malleable iron seem even more difficult to reconcile with the ordinary conceptions of precipitation hardening and embrittlement.

Why, for example, should heating to 450 degs. Cent. (842 degs. Fahr.) cause precipitation in malleable which is already a very slowly cooled material? It has been suggested that after quenching from 650 degs. Cent. (1202 degs. Fahr.), precipitation on subsequent heating to 450 degs. Cent. (842 degs. Fahr.) occurs throughout the grain instead of in the more damaging location in the grain boundaries of the annealed malleable reheated to 450 degs. Cent. (842 degs. Fahr.)

This still does not answer the preceding question, and it also brings up another problem. If the effect of heating to 450 degs. Cent. (842 degs. Fahr.) is that of precipitation, why should quenching from this temperature, but not slow cooling, cause brittleness? Apparently, that the slower cooling produces particles larger than the critical size to cause embrittlement is not the answer, because the time of holding at 450 degs. Cent. (842 degs. Fahr.)—presumably a precipitation temperature—seems to have a minor effect on embrittlement.

A way out is, perhaps, to borrow Dean's suggestion⁴ that solution and not precipitation may account for the blue-heat phenomena in steel. In annealed malleable, which is not brittle, it might be assumed that some precipitation occurs in the grain boundaries, this being relatively harm-

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⁴L. R. Van Wert, "Some Notes on Blue Brittleness," *Transactions Am. Inst. Mining Met. Engr., Iron and Steel Division*, 1931, pp. 230-238; discussion, pp. 238-246.

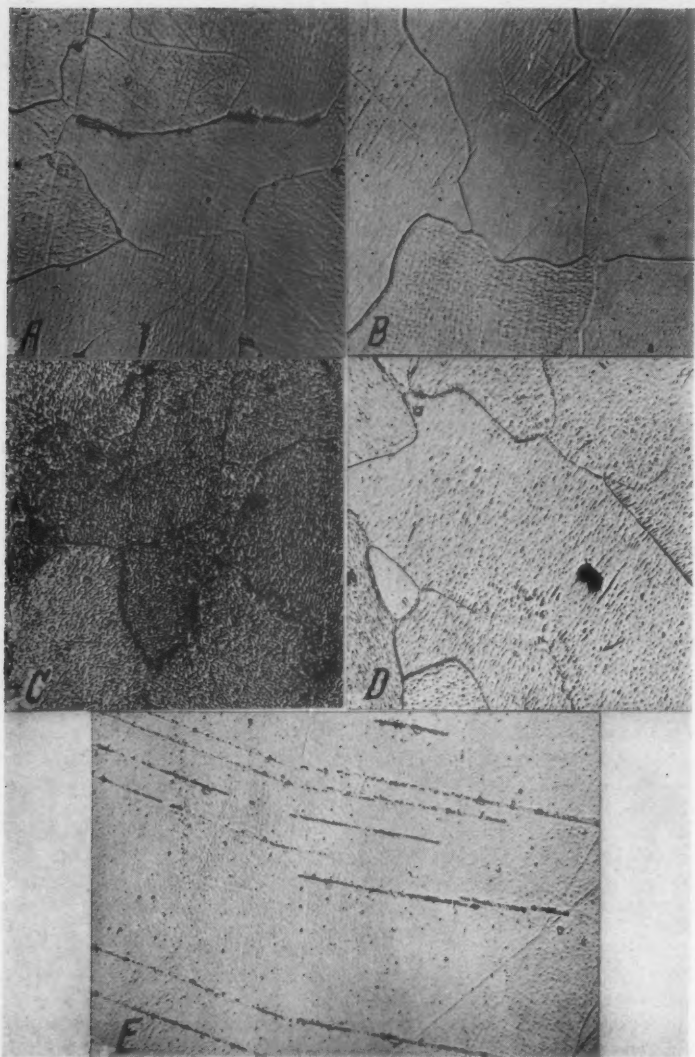


FIG. 25—PRECIPITATION EFFECTS IN ARMCO IRON. X500. NOTE (1) SOLUTION OF GRAIN BOUNDARY CARBIDES ON QUENCHING FROM 650 DEGS. CENT. (1202 DEGS. FAHR.); (2) DARKENING AFTER ETCHING WITH FRY'S MICRO-REAGENT IN THE "AS RECEIVED" CONDITION BUT NOT AFTER QUENCHING FROM 650 DEGS. CENT.; AND (3) PRECIPITATION IN SLIP LINES AFTER COLD WORK AND TEMPERING. A AND C: "AS RECEIVED." B AND D: QUENCHED FROM 650 DEGS. CENT. E: QUENCHED FROM 650 DEGS. CENT., SLIGHTLY DEFORMED AND TEMPERED 8 DAYS AT 200 DEGS. CENT. (392 DEGS. FAHR.). A, B AND E ETCHED WITH 5% PICRIC ACID IN ALCOHOL, C AND D ETCHED WITH FRY'S MICRO-REAGENT.

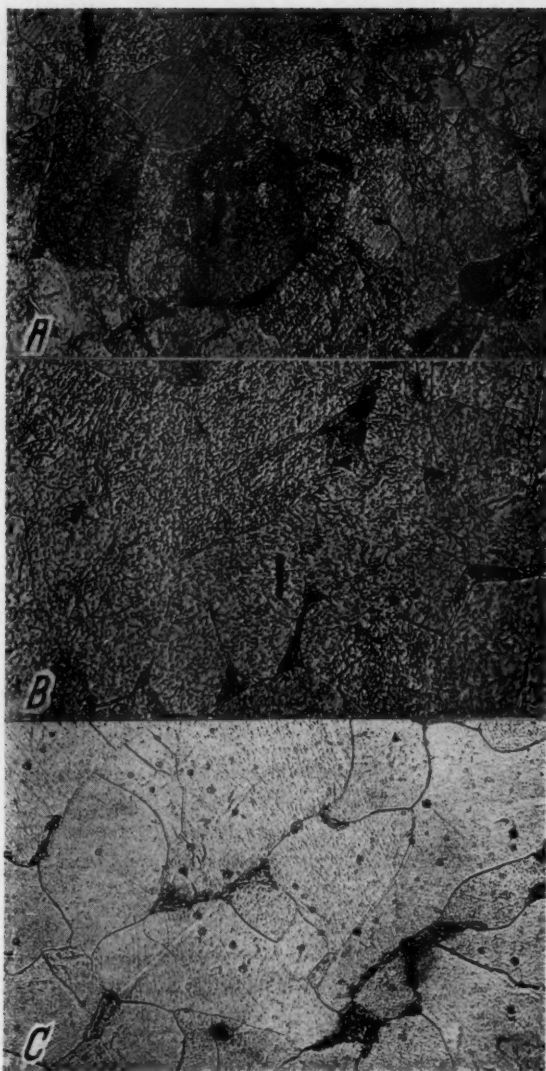


FIG. 26—PRECIPITATION EFFECTS IN BESSEMER STEEL. ETCHED WITH FRY'S MICRO-REAGENT, X500. A: "AS RECEIVED"; DARKENING AS RESULT OF PRECIPITATION. B: HEATED 2 WEEKS AT 100 DEGS. CENT. (212 DEGS. FAHR.); APPARENT COALESCENCE. C: QUENCHED FROM 650 DEGS. CENT. (1202 DEGS. FAHR.); SOLUTION.

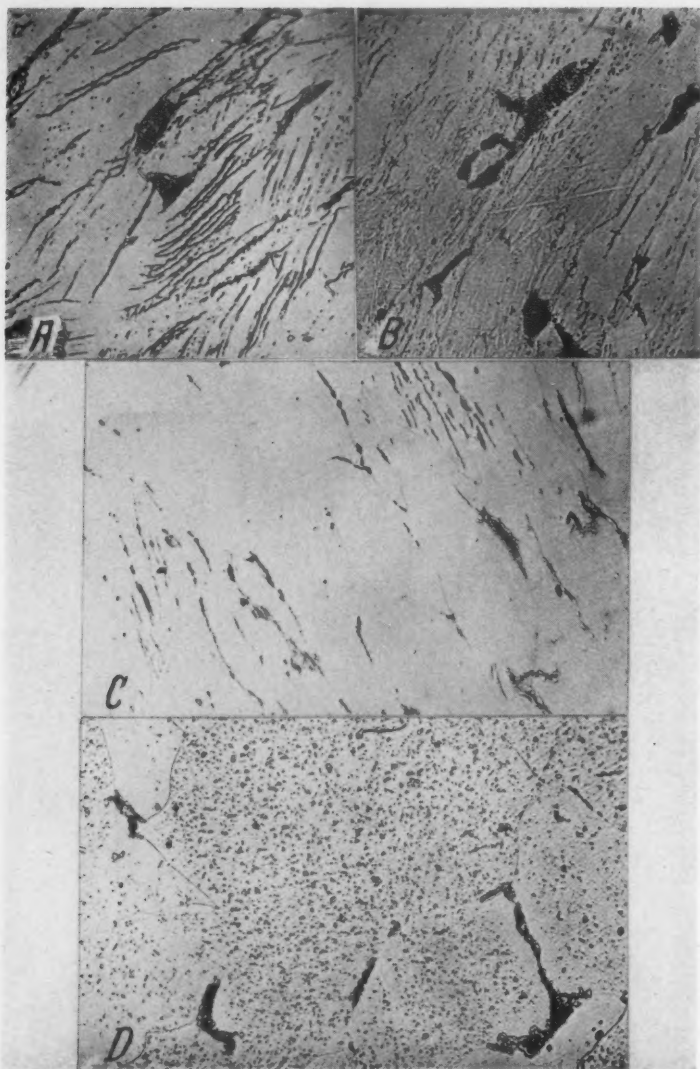


FIG. 27—PRECIPITATION EFFECTS IN BESSEMER STEEL. X500. A AND C: COMPRESSED THEN HEATED 2 WEEKS AT 100 DEGS. CENT. (212 DEGS. FAHR.); NOTE PRECIPITATION IN SLIP LINES. B: COLD WORKED RING ABOUT A PUNCHED HOLE, HEATED 2 WEEKS AT 100 DEGS. CENT. D: QUENCHED FROM 650 DEGS. CENT. (1202 DEGS. FAHR.), THEN HEATED 8 DAYS AT 200 DEGS. CENT. (392 DEGS. FAHR.); NOTE PRECIPITATION THROUGHOUT THE GRAIN. A, B AND D ETCHED WITH 5% PICRIC ACID IN ALCOHOL; C ETCHED WITH BOILING SODIUM PICRATE.

less. On heating to 450 degs. Cent. (842 degs. Fahr.) there might be incipient solution which on quenching would lead to brittleness, whereas on slow cooling reprecipitation might occur accompanied by relative ductility. Prior quenching from 650 degs. Cent. (1202 degs. Fahr.) might dissolve the grain boundary impurities and diffuse them, so that subsequent quenching from 450 degs. Cent. (842 degs. Fahr.) would not be injurious.

Such assumptions, however, without more basis are as arbitrary as the one the author is forced to make that quenched cementite in the grain boundaries is brittle, whereas slowly cooled cementite is not. Such theories are more or less futile and perhaps needless, since a persistent attack on the problem by ordinary metallographic methods without undue refinements ought to give evidence for reaching a definite conclusion.

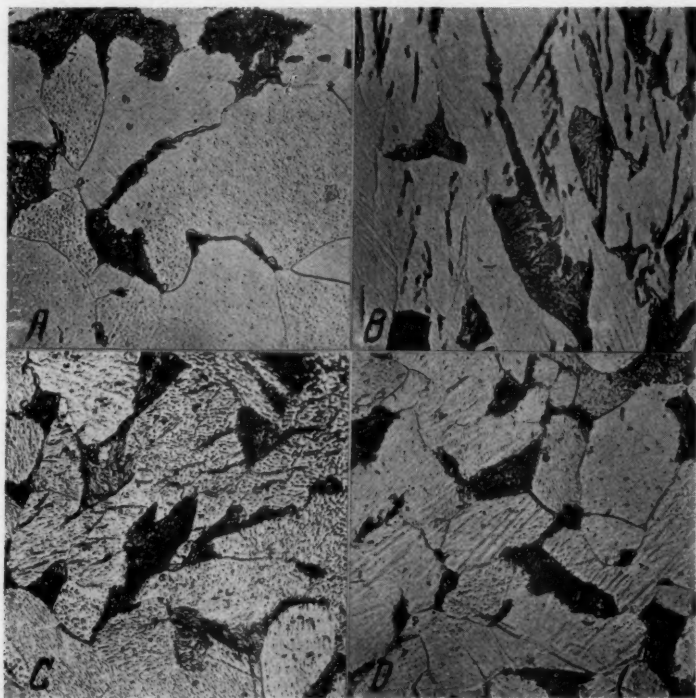


FIG. 28—PRECIPITATION EFFECTS IN OPEN-HEARTH STEEL. X500. A: QUENCHED FROM 650 DEGS. CENT. (1202 DEGS. FAHR.), HEATED 8 DAYS AT 200 DEGS. CENT. (392 DEGS. FAHR.); VERY LITTLE OR NO PRECIPITATION. B: COMPRESSED THEN HEATED 8 DAYS AT 200 DEGS. CENT.; SLIGHT PRECIPITATION EFFECTS IN SLIP LINES. C: "AS RECEIVED"; NOTE ATTACK AND DARKENING. D: QUENCHED FROM 650 DEGS. CENT.; NOTE SMOOTHNESS OF SURFACE. A AND B ETCHED WITH 5% PICRIC ACID IN ALCOHOL; C AND D ETCHED WITH FRY'S MICRO-REAGENT.

The accompanying Figs. 25 to 30, inclusive, indicate that precipitation effects in iron and steel can be revealed microscopically after cold working and after "solution" and "precipitation" heat treatments, and with the aid of Fry's copper-bearing micro-etching reagent.⁵ Such precipitation effects were brought out distinctly in Bessemer steel (Figs. 26 and 27), which is decidedly susceptible to embrittlement, by cold work and reheating to the blue-heat temperature region, less plainly in open-hearth steel (Fig. 28), which is very much less susceptible, and not at all in the German Izett⁶ steel (Fig. 29), which possesses remarkable immunity against such embrittlement. Similar precipitation effects were not re-

⁵ A. Fry, "Strain Line Etching," *Stahl und Eisen*, vol. 41, 1921, p. 1093.

⁶ G. Neuendorff, "Izett Steel, What It Is and What It Is Used For," *Metals and Alloys*, vol. 3, 1932, p. 61.

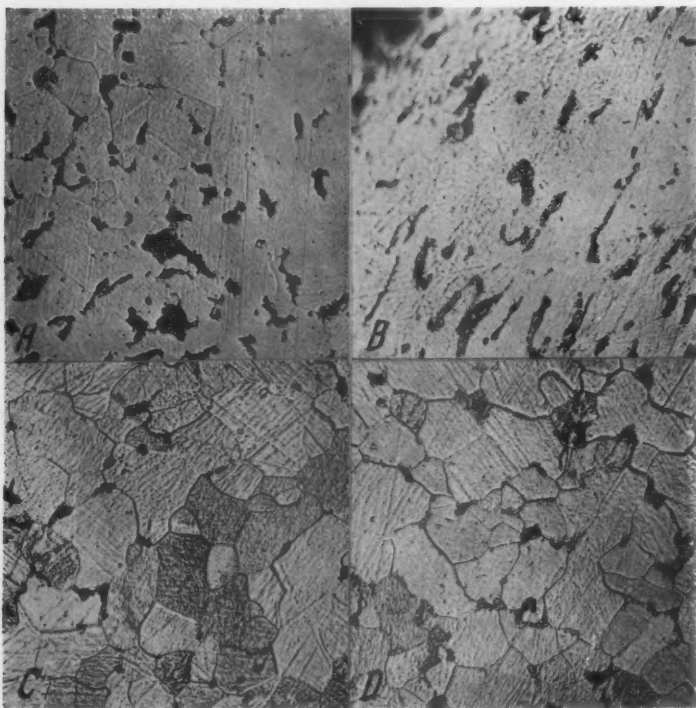


FIG. 29—ABSENCE OF PRECIPITATION EFFECTS IN INGOT STEEL. X500. A: QUENCHED FROM 650 DEGS. CENT. (1202 DEGS. FAHR.), HEATED 2 WEEKS AT 200 DEGS. CENT. (392 DEGS. FAHR.) B: COMPRESSED THEN HEATED 2 WEEKS AT 200 DEGS. CENT. C: "AS RECEIVED." D: QUENCHED FROM 650 DEGS. CENT. A AND B ETCHED WITH 5% PICRIC ACID IN ALCOHOL; C AND D ETCHED WITH FRY'S MICRO-REAGENT.

vealed distinctly in malleable iron, but sufficient work on this material has not as yet been done.

The micrographs after etching with Fry's micro-reagent before and after quenching from 650 degs. Cent. (1202 degs. Fahr.) indicate how ordinary iron and steel, which we usually consider free from precipitation phenomena, are really permeated with such effects. The marked roughening and darkening of the surfaces before quenching from 650 degs. Cent. (1202 degs. Fahr.) are in marked contrast to the smoother surfaces after quenching, except in the Izett steel and in the malleable iron, in which the appearance was about the same before and after quenching from 650 degs. Cent. (1202 degs. Fahr.)

Compare *c* and *d* Fig. 25, *a* and *c* Fig. 26, *c* and *d* Fig. 28, *c* and *d* Fig. 29, *a* and *b* Fig. 30. In the cold-worked specimens of Armco iron (Fig.

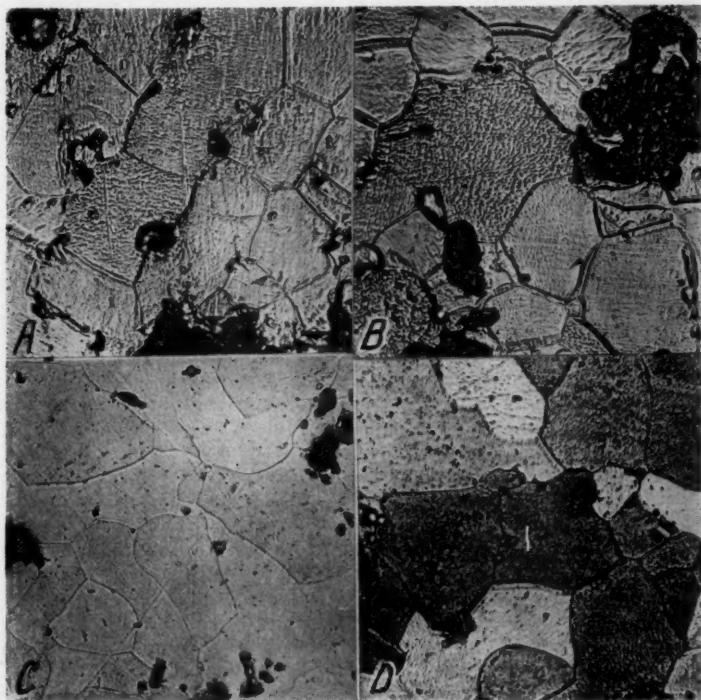


FIG. 30—APPARENT ABSENCE OF DECIDED PRECIPITATION EFFECTS IN MALLEABLE CAST IRON. X500. A: "AS RECEIVED." B: QUENCHED FROM 650 DEGS. CENT. (1202 DEGS. FAHR.). C AND D: QUENCHED FROM 650 DEGS. CENT., TEMPERED 8 DAYS AT 200 DEGS. CENT. (392 DEGS. FAHR.); SHOWS SOME EVIDENCE OF PRECIPITATION. A, B AND D ETCHED WITH FRY'S MICRO-REAGENT; C ETCHED WITH 5% PICRIC ACID IN ALCOHOL.

25-d) and Bessemer steel (Fig. 27-a, b, c) precipitation occurred along slip lines after long-time tempering at 100 and 200 degs. Cent. (212 and 392 degs. Fahr.)

In Fig. 27-c the darkening in the slip lines appeared after etching with hot alkaline sodium picrate. Since this reagent has no tendency to "eat out" as does an acid reagent, this may be taken as supporting evidence that the darkening in the slip lines is really due to precipitation and is not merely an etching effect.

It should be emphasized that the precipitation effects were revealed after prolonged heating at 100 and 200 degs. Cent. (212 and 392 degs. Fahr.) They did not appear on heating at 450 degs. Cent. (842 degs. Fahr.), so that the question whether solution or precipitation occurs at this temperature (450 degs. Cent., or 842 degs. Fahr.) is still open. The point is that we probably can go a long way toward settling the matter by this means of attack.

The behavior of steel and of malleable in regard to embrittlement have their similarities and also their differences, and these might be mentioned since they may reflect variations in the underlying causes. In most steel, heating to 450 degs. Cent. (842 degs. Fahr.) alone does not cause appreciable embrittlement; this occurs only after severe cold work. In malleable iron, of course, prior cold work is not required.

In malleable iron, embrittlement seems to be associated with a grain boundary weakness,⁷ whereas in steel it appears more likely to be a weakness along certain cleavage planes of the grains. It has been suggested that ordinarily precipitation effects occur on crystallographic planes.⁸ In steel, quenching or slow cooling after heating to 450 degs. Cent. (842 degs. Fahr.) apparently makes no difference, whereas in malleable there is a pronounced difference.

The main similarity between the two is that the temperature range of heating which causes brittleness (after cold work in steel) is about the same in both. This is made strikingly evident by comparing the curves for malleable iron in the author's paper with those for steel in the article by Neuendorff.⁶

At any rate, the similarity between the two is sufficiently close so that the technique which recently has been used for the study of the blue-heat phenomena in steel should be applied to malleable. Among these are tensile tests in the blue-heat region and possibly torsion tests to observe the "steps" in the stress-strain curves.⁴ The use of cold work, prolonged low-temperature treatments, and Fry's micro-reagent has already been indicated.

It now is recognized that we can hardly hope for a clear-cut solution of the cause of the embrittlement phenomena in steel unless the variables of chemical composition are separated and the effects of the different impurities studied one at a time. An attempt to do the same should be made for malleable.

⁷W. R. Bean, "Deterioration of Malleable in the Hot-Dip Galvanizing Process," *Foundry*, vol. 51, 1923, pp. 447-455.

⁸Beryllium, Siemens Konzern, translated from the German by Rimbach and Michel. The Chemical Catalog Company, 1932. See articles on Age-Hardening of Copper-Beryllium Alloys.

The results of such a study may do more than merely solve a theoretical point, but may be fruitful practically as is manifested by the success the Germans have had in developing the non-aging Izett steel. The embrittlement of malleable iron has been a problem in the industry for 20 years and, now that promising means are at hand for arriving at a solution, it would seem that a new concerted attack on it is highly in order. A modest effort is being made at Battelle Memorial Institute with the aid of a graduate student from Ohio State University and the cooperation of Dr. H. A. Schwartz.

WRITTEN DISCUSSION

H. A. SCHWARTZ:* The subject matter of Dr. Kikuta's paper is one which at the moment is attracting considerable attention among malleable metallurgists both on account of its practical applications and its theoretical significance. The present writer certainly is in accord with Dr. Kikuta to the extent of believing that the so-called galvanizing embrittlement of malleable, which has really an effect of heat treatment, is in some manner related to grain boundary conditions, and that it is at least possible that this relation takes the form of the precipitation of a weakening constituent in the grain boundaries.

It is the writer's understanding, both from reading the paper and from personal conference with Dr. Kikuta, that the latter feels that malleable iron cooled slowly through the dangerous embrittling range precipitates traces of certain carbides in the grain boundaries, but that if the iron be quenched from the usual 600 degs. Cent. (1112 degs. Fahr.) temperature, this precipitation in the grain boundaries does not occur. It would be rather easy to suppose that in the latter event any precipitation would be within the body of the grain instead.

The writer is not prepared to disprove the Kikuta supposition; indeed, he is greatly interested in seeing it advanced. He does not feel, however, that any positive evidence has been furnished of the existence of the inclusions to which the effect is ascribed.

Some years ago there was occasion in the writer's laboratory to study the resistivity and permeability of metal before and after it was reclaimed from the embrittled condition by subsequent heating to something above 600 degs. Cent. (1112 degs. Fahr.) and quenching. We did not cover a continuous series of temperature readings up and down as did Dr. Kikuta, but merely made the observations over a range from room temperature to about 100 degs. Cent. (212 degs. Fahr.) for resistivity, and at 16 and 36 degs. Cent. (68.8 and 96.8 degs. Fahr.) for permeability. In no case were we able to detect any change in electro-magnetic properties produced by the reclaiming treatment. The methods used were such that changes of less than one per cent of the observed values would not have been recorded.

* Manager of Research, National Malleable & Steel Castings Co., Cleveland.

If conclusions are to be drawn from very slight differences of resistivity in a sample subjected to certain heating and cooling rates, then it always is possible that slight and unsuspected temperature differences may produce a considerable effect.

Lacking detailed data as to the conditions of the Kikuta resistance observations, we cannot say whether or not the slight shift in his resistivity curves on heating and cooling might be due to this cause. The writer, therefore, distinctly does not attack the correctness of Dr. Kikuta's results but merely points to a possible source of error which may, of course, have been properly eliminated in the original observations.

The problem also was considered in our laboratory from the point of view of grain orientation. Norman Goss made for us a considerable number of Lane X-ray crystallograms, with entirely negative results. The crystallograms occasionally show insignificant differences of lattice strain, possibly resulting from the heat treatment; but they show no evidence whatever of any preferred orientation either in the metal as annealed or embrittled, or as given the prevention treatment.

In the paper, the statement is made that "something might be seen at 1000 diameters." This particular wording is not quite clear to the present writer, for it might mean that either observations at this magnification were not made or else that they were made and the observer was not perfectly sure but thought he saw something.

Specimens of metal showing intergranular brittleness have been examined in the writer's laboratory at the highest magnifications here available, involving the use of an oil-immersion objective, focal length 1.9 mm. and a 20X eye-piece. Under these conditions we have not been able to satisfy ourselves that there was any constituent present in the grain boundaries. Such a negative result, of course, always is unsatisfactory, for there may be other manipulative conditions which would have been more successful.

REPLY BY AUTHOR

T. KIKUTA: Mr. Schwartz measured the resistivity and permeability of malleable cast iron before and after it was reclaimed from the embrittled condition by subsequent heating to something above 600 degs. Cent. (1112 degs. Fahr.) and quenching, but he could detect no change in electromagnetic properties produced by the reclaiming treatment. Carbon content of the carbon steel or malleable iron to make a solid solution below the A_1 point is very small (0.04 per cent), so that it is difficult to detect the slight difference of the resistivity and magnetic property of the metal produced by the reclaiming treatment.

The author wishes to give here some details of his experiment to clear up a point in Mr. Schwartz' question. An electric resistance furnace

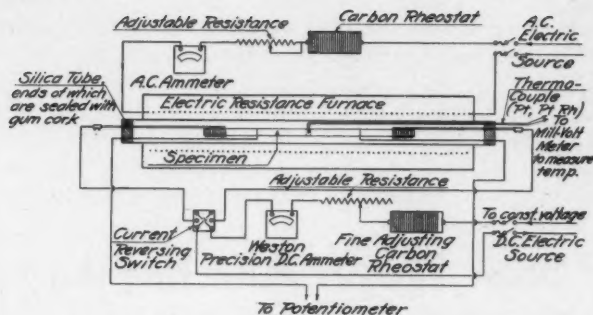


FIG. 31.—WIRING DIAGRAM OF EXPERIMENTAL FURNACE.

used in the experiment was 500 mm. (19.67 in.) in length and 40 mm. (1.57 in.) inside diameter and wound antiparabolically with a nichrome wire to permit good uniformity of the temperature over a length of 200 mm. (7.87 in.) A specimen was placed in the uniform temperature range of the furnace and heated and cooled uniformly.

To measure the temperature of the specimen, a thermocouple of platinum and platinum-ten per cent rhodium was inserted in a hole 2 mm. thick, drilled at a middle point of the specimen. The thermocouple and the specimen were insulated from each other. The current flowing through the specimen was regulated precisely to 3 amps. with two adjustable rheostats, and the potential drop was measured by a potentiometer of the Leeds & Northrup type of 10^{-6} volts, so that the precise degree of the resistance was obtained to 0.1 per cent of the observed value.

A wiring diagram of this experimental furnace is shown in Fig. 31. The observations were carried out on every two specimens similarly treated, and the same results were obtained in each case, as shown in Figs. 21 to 23.

The microscopic test of the high magnification carried out in Mr. Schwartz' laboratory is of interest to the author. However, he did not explain about the etching reagent used in his experiment. It seems that there may be some etching reagents besides those ordinarily used, such as an alcoholic solution of picric acid or of nitric acid, to detect such slight carbides on the grain boundary.

Some Factors Affecting the Cleanliness of Steel Castings

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PITTSBURGH

Abstract

In producing steel of uniform cleanliness and good physical properties, it is necessary to be careful not only of the choice of deoxidizers but also of the preparation of the heat for deoxidation. A good action in the bath during the refining period and a slag of the proper viscosity, in either basic or acid practice, are necessary for proper preparation of the bath for deoxidizing additions. Methods of controlling bath action and slag viscosity are given in detail in the text. The action of deoxidizers is to form an insoluble oxide which must be floated out of the metal. The rate of elimination of non-metallic particles depends on their size and this, in turn, is determined by the deoxidizers added. Manganese-silicon alloys form larger inclusions than any combination of deoxidizers studied at this time. The action of aluminum in causing low ductility is the change in the location of sulphide inclusions in the cast steel. A hypothesis for this change in location is discussed. A very low sulphur steel would appear to be necessary for consistent production of high ductility in aluminum treated steels.

1. In any discussion of inclusions in steel it must be kept in mind that there are three sources for the entrance of such non-metallic matter. The first source is non-metallic matter in the raw materials charged or added during the working of the heat. The

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† Research Engineer, Metallurgical Advisory Board to Carnegie Institute of Technology.

second source is deoxidation, whereby soluble iron oxide is converted into insoluble oxide of manganese, silicon, aluminum, or oxides of any other deoxidizers used. The third source is the erosion of the spout, the ladle lining, the nozzle, and, in the case of steel castings, the mold. Inclusions from this third source are rare, when present usually are readily discernible to the naked eye, and are in general a minor factor in steel cleanliness.

ELIMINATION OF INCLUSIONS DURING WORKING OF HEAT

2. In any heat of steel the charge always contains a certain amount of non-metallic matter. This consists mainly of Al_2O_3 and SiO_2 . The amount varies widely and depends on the cleanliness of the raw materials used. It has been found¹ that pig iron varies in cleanliness over exceedingly wide limits. The variation in the cleanliness of pig iron is so much greater than the variation of cleanliness of scrap that the major variations in the cleanliness of the charge may be traced to the pig iron rather than to the scrap.

3. There are two ways in which inclusions from the charge may be eliminated during the working of the heat: (1) Intimate contact of slag and metal brought about by proper agitation of the bath, and rapid absorption of the non-metallic matter obtained by proper slag viscosity, together with a long enough time of working, and (2) by fluxing the inclusions by MnO or FeO dissolved in the metal. Low-carbon steels, before deoxidation are usually lower in this type of inclusion than high-carbon steels because there generally is more iron oxide dissolved in the steel at the lower carbon content.

4. The silicates in the charge are gradually eliminated from the time the heat is melted until it is ready for deoxidation. An average of 14 heats¹ showed that the average silicate content of the charge was 0.023 per cent, and of the bath before deoxidation, 0.009 per cent. These heats were worked from 2 to 4 hours between melt-down and tap.

5. If the heat is melted down to the desired carbon and tapped immediately there is little chance of eliminating inclusions originating in the charge. In order to get the best elimination under any conditions, the slag must be at the proper fluidity whether it is acid or basic.

¹ U. S. Bureau of Mines, *Bulletin No. 308*, 1929.

Basic Slags

6. In conditioning the slag for the elimination of non-metallic matter, it must be remembered that high FeO confers fluidity but at the same time causes excessive oxidation of the metal, which may be quite harmful when the heat is deoxidized. If a slag contains too much lime it will be too viscous. Such a slag may be readily thinned out with fluorspar. The use of too much fluorspar is dangerous, for, whereas it takes only a small amount of spar to thin out a slag, a great deal of lime is required to thicken the slag if the heat has been over-sparred.

7. If the slag is too high in magnesia, it is difficult to get it in the proper condition. The slag will be quite grainy and fluorspar will not act upon it as readily as upon high-lime slag. For best results, the magnesia should be kept between 5 and 8 per cent, and the CaO between 40 and 45 per cent.

8. If the slag is too thin, burnt lime or dolomite may be used for thickening, depending upon the MgO content of the slag. For example, if a slag usually contains about 5 per cent MgO , it is well to use dolomite for thickening because MgO will thicken the slag more rapidly than CaO . On the other hand, if the slag usually contains 8 per cent MgO , it is advisable to use burnt lime. The excessive use of fluorspar may be avoided by charging enough manganese as high-manganese pig iron so that the slag contains from 8 to 10 per cent MnO .

9. FeO in the slag is best controlled by carefully controlling the melting-down period and using as little ore as is consistent with speed of working. It is better to melt down rapidly and at a high temperature than slowly at a lower temperature.

10. Reagan² has shown the relation between melting down and oxidation of the slag. Viscous slags may be thinned out by an increase in temperature, but it is dangerous to use this method of obtaining the proper slag viscosity because, if the slags are kept heavy until the proper time for the temperature increase, the time for scrubbing out inclusions in the steel will be too short.

Acid Slags

11. The best method of controlling the viscosity of the slag is to use the proper amount of CaO and to regulate the tempera-

² American Institute of Mining and Metallurgical Engineers, *Technical Publication No. 469*, 1932.

ture so that not too much silica is picked up from the furnace lining during the course of the heat. By regulating the silica pick-up, the slag may be kept at the proper fluidity until the heat is ready for deoxidation. FeO and MnO are interchangeable so far as viscosity is concerned. It is possible, therefore, to deoxidize the slag without interfering with viscosity, provided manganese is used as a deoxidizer.

12. It is advisable to use a high-manganese charge. This may be obtained from high manganese pig iron or from low manganese pig iron plus spiegel. When CaO is added to the slag, some of the iron oxide is freed from its combination with silica. The released FeO diffuses into the metal; total FeO is lowered.

13. After this step has been taken, it is advisable to add manganese to the bath from time to time as ferromanganese or spiegel, and thus reduce the iron oxide content of the slag without interfering with its fluidity. Jacobs and Herty³ have shown that when spiegel is added with the ore the silicate content of the metal is reduced considerably, on account of the fluxing action of the MnO formed by the oxidation of the manganese in the spiegel.

14. In order to effect the best elimination of non-metallic matter from the acid charge, it is essential that a brisk boil take place throughout the major portion of the working period. This is quite easy to accomplish by the proper use of ore and manganese.

THE DEOXIDATION OF BASIC STEEL

15. When the heat is ready for deoxidation it contains from 0.15 to 0.25 per cent FeO, which must be eliminated to a large extent. If the steel is insufficiently deoxidized, blow holes will be found in the surface and body of the casting.

16. In order to accomplish the deoxidation it is necessary to use metals which will react with the iron oxide and whose deoxidation products will not react with carbon. The three deoxidizers in common use are manganese, silicon and aluminum, these being given in order of their strength.

17. Manganese alone, unless added in very large amounts, will not prevent the formation of blow holes; in steel castings it is necessary to use silicon, and in some instances both silicon and aluminum. In order to prevent the retention of the deoxidation

³ *Transactions, American Society for Steel Treating*, vol. 19, no. 3, p. 271, 1932.

Table 1

Size of Inclusion, cm. $\times 10^4$	Maximum Rising Velocity, inches per minute.	Least Time Required to Rise Through, in minutes.	
		30-in. Open-Hearth Bath.	12-ft. Ladle.
5	0.061	432.0	2360.0
10	0.245	122.0	587.0
50	6.12	4.93	23.60
100	24.45	1.22	5.87
500	612.00	0.05	0.24

products, it always is necessary to use some manganese with the silicon or aluminum.

18. The best practice in deoxidation is to deoxidize as thoroughly as possible in the furnace and to complete the deoxidation in the ladle. When the heat is deoxidized in the furnace, the deoxidation products (non-metallic inclusions) are more easily eliminated from the metal than if the deoxidation was carried out entirely in the ladle, because there is less distance for the inclusions to rise and enter the slag.

19. If silicon alone is used as a furnace deoxidizer, the silica particles are eliminated quite slowly.⁴ If manganese is used in conjunction with the silicon as a separate alloy, much cleaner steel is obtained; and if the two are used as an alloy containing a ratio of manganese to silicon of from 4:1 to 6:1, the elimination is more rapid than with either of above-mentioned methods. The reason for this is that much larger particles are formed on deoxidation,⁵ and the larger the particle the more rapid its rise through the metal bath.

20. The rate of rise of particles of different size is given in Table 1. From this table the importance of forming a large particle can be readily seen.

21. While the silicates are being eliminated from the furnace, iron oxide is diffusing from the slag into the metal. If the heat is kept in the furnace too long after deoxidation, the work of this deoxidation will have been nullified by the rise in the FeO content of the metal. If 0.10 per cent of silicon is added to the bath as silicon pig or as a silicon-manganese alloy, from 10 to 15 minutes are required for the elimination of the silicon.

⁴ *Cooperative Bulletin 38*, Metallurgical Advisory Board to U. S. Bureau of Mines and Carnegie Inst. of Technology, 1930.

⁵ U. S. Bureau of Mines, *Report of Investigations No. 3081*, Feb. 1931.

22. As soon as the silicon is eliminated, the iron oxide content of the bath begins to build up, as shown in Table 2. Zero time is taken when the silicon content of the metal has reached 0.01 per cent. The depth of bath in these heats was 24 inches.

23. If the non-metallic particles are of such a form that they are very slowly eliminated, it is obvious that FeO in the metal will be high before complete elimination occurs. On the other hand, if the proper proportion of deoxidizers is used, the non-metallic particles can be eliminated in from 10 to 15 minutes and the heat should then be tapped immediately, else the FeO in the metal will rise as shown in Table 2.

24. During the deoxidation period the slag should be reasonably heavy, in order to prevent too rapid reoxidation of the metal. It often is true that when the heat is deoxidized, the slag tends to thin out on account of the SiO_2 and MnO which enter from the metal, and from the increased temperature resulting from the deoxidation.

25. In such a case it is best to add dolomite or burnt lime, depending upon the magnesia content of the slag. Particular care should be taken to prevent any action at the ends of the furnace, and a few shovels of dolomite on each end after the deoxidizers

Table 2

INCREASE OF FeO IN METAL AFTER SILICON ELIMINATION

Heat No.	Time, hour.	Time, in minutes.	FeO in Metal, per cent
1396.....	2:05	0.0	0.119
	2:075	2.5	0.122
	2:105	5.5	0.155
	2:13	8.0	0.160
	2:16	11.0	0.165
	2:18	13.0	0.205
2105.....	2:56	0.0	0.102
	3:00	4.0	0.123
	3:04	8.0	0.137
	3:075	11.5	0.202
6841.....	2:24	0.0	0.050
	2:27	3.0	0.098
	2:30	6.0	0.105
	2:33	9.0	0.135
	2:36	12.0	0.173
	2:39	15.0	0.188

are added usually is sufficient to prevent rapid reoxidation of the metal.

26. After the heat is tapped, the additions are added in the ladle to make the final specifications and to complete deoxidation. If aluminum is used in the ladle it should be distributed as well as possible and not added all at one time. If the aluminum is not distributed, the proper effect on degasification is not obtained and very great segregation of alumina is apt to occur.

DEOXIDATION OF ACID STEEL

27. The deoxidation of acid steel, either open hearth or electric, is in general much simpler than in basic steel because the slag can be controlled to a much greater extent. For example, by the proper use of manganese during the working of the heat, the iron oxide in the slag may be reduced to a low value.

28. Acid open-hearth slags worked without manganese will give the following average analysis: FeO 17 per cent, MnO 20 per cent, SiO₂ 56 per cent, CaO 4 per cent. Heats worked with manganese show an average analysis of FeO 12 per cent, MnO 25 per cent, SiO₂ 56 per cent, CaO 4 per cent.

29. By reducing the amount of FeO in the slag from 17 per cent to 12 per cent, it is possible to slow down greatly the diffusion of iron oxide from slag to metal, thereby minimizing reoxidation after the deoxidizers are added. Furthermore, when the FeO is lowered to 12 per cent, enough silicon is reduced into the metal so that very little extra must be added to meet the final specifications.

30. The necessary silicon may be added as ferro-silicon or as a silicon-manganese alloy. If 0.08 per cent or more silicon is to be added, it is preferable to add a silicon-manganese alloy. Otherwise, ferrosilicon may be added without the danger of the formation of very many silica particles. All deoxidizers, except any aluminum necessary, should be added in the furnace.

INCLUSIONS IN CAST STEEL

31. There are two general types of inclusions in cast steel, the oxide and the sulphide. The oxides include silicates and Al₂O₃. Inasmuch as oxides and sulphides are mutually soluble in the liquid state, there is almost always some oxide in a sulphide inclusion and, conversely, some sulphide in oxide inclusions.

32. Aluminum silicate and Al_2O_3 usually occur in small clusters which are sometimes found around the grains and sometimes within the grains. Silicates are present as globules and are to be found located either in the grain boundaries or within the grain itself.

33. In the liquid steel the silicates may be quite small, but they coalesce when sufficiently concentrated to form larger globules.⁶ The growing crystals push the small particles ahead until free crystallization sets in, when the inclusions are trapped wherever they may be at this time. Concentration of silicates at the point of free crystallization is shown in the data for an ingot⁷ as given in Table 3.

34. Al_2O_3 acts in much the same way, except that the segregation is not so marked.⁷ Therefore, the type and concentration of silicates and Al_2O_3 depend upon the size of the castings and the amount present in the liquid steel immediately before the metal is cast.

35. In the rolling of steel the effect of sulphur in causing red-shortness is overcome by additions of manganese. The following is quoted from a paper⁷ by one of the authors: "Sulphides are in solution in liquid steel, and their mode of occurrence in the solid metal depends on the manganese content and on the rate of solidification. It has been shown⁸ that the amounts of manganese

⁶ *Cooperative Bulletin No. 36*, U. S. Bureau of Mines, Carnegie Institute of Technology, and Metallurgical Advisory Board.

⁷ *Transactions*, Amer. Soc. for Steel Treating, vol. 19, no. 1, p. 1, 1931.

⁸ Bureau of Mines, *Report of Investigations No. 2817*, July, 1927.

Table 3

Position.	Sample No.	Per cent SiO_2 .
Skin of ingot.....	1	0.017
	2	0.019
	3	0.016
	4	0.019
	5	0.020
	6	0.026
Change of crystallization from dendritic to equiaxed.	7	0.057
	8	0.095
	9	0.023
	10	0.031
	11	0.024
Center of ingot.....		

and sulphur which may be mutually present in liquid pig iron increase rapidly with increasing temperature.

36. "At 1475 degs. Cent. (2690 degs. Fahr.) the approximate freezing point of a 0.40 per cent carbon plain-carbon steel, the solubility product, per cent Mn times per cent S, equals 0.90 in pig iron. From data obtained in an earlier research on iron containing less than 0.05 per cent of carbon, the solubility product was approximately 0.50 at about 1550 degs. Cent. (2825 degs. Fahr.)

37. "It may be stated positively, therefore, that in a steel containing 0.70 per cent of manganese and 0.035 per cent of sulphur, all the sulphur would remain in solution until the steel began to crystallize, because the product ($Mn \times S$) equals 0.0245. It is probably the concentration of sulphur in the liquid between crystallites that promotes the precipitation of manganese and sulphide.

38. "Slow cooling, of course, would promote the concentration of sulphur because the mother liquor is not as completely trapped as in a rapidly cooled test. The rate of cooling, therefore, has a considerable effect on the type of sulphide.

39. "For example, in high-manganese high-sulphur steels a splash test will show very little manganese sulphide. On the other hand, the interior of a slowly cooled ingot will show manganese sulphide is the predominant non-metallic present. Although the term "manganese sulphide" is commonly used to designate the globular sulphide inclusion in cast steel and the elongated sulphide inclusion in rolled steel, the inclusion is actually an iron-manganese sulphide."

40. Figs. 1-A and 1-B are taken from the skin and center, respectively, of a 12,000-lb. ingot which was cast from steel deoxidized with manganese and silicon. This steel contained 0.33 per cent C, 0.51 per cent Mn and 0.21 per cent Si. The sulphur in the sample corresponding to Fig. 1-A was 0.026 per cent; in the sample corresponding to 1-B, it was 0.025 per cent.

41. The steel in the skin of the ingot, Fig. 1-A, had been so quickly chilled that there was little opportunity for the sulphides to coalesce. In the center of the ingot, Fig. 1-B, the sulphides are globular and show that there has been sufficient time between the precipitation of the sulphide and complete solidification for coalescence to take place.



FIG. 1—FORM OF SULPHIDES IN SKIN OF INGOT (A) AND CENTER OF INGOT (B).
STEEL DEOXIDIZED WITH MANGANESE AND SILICON. ETCHED WITH PICRIC ACID.
100 X.

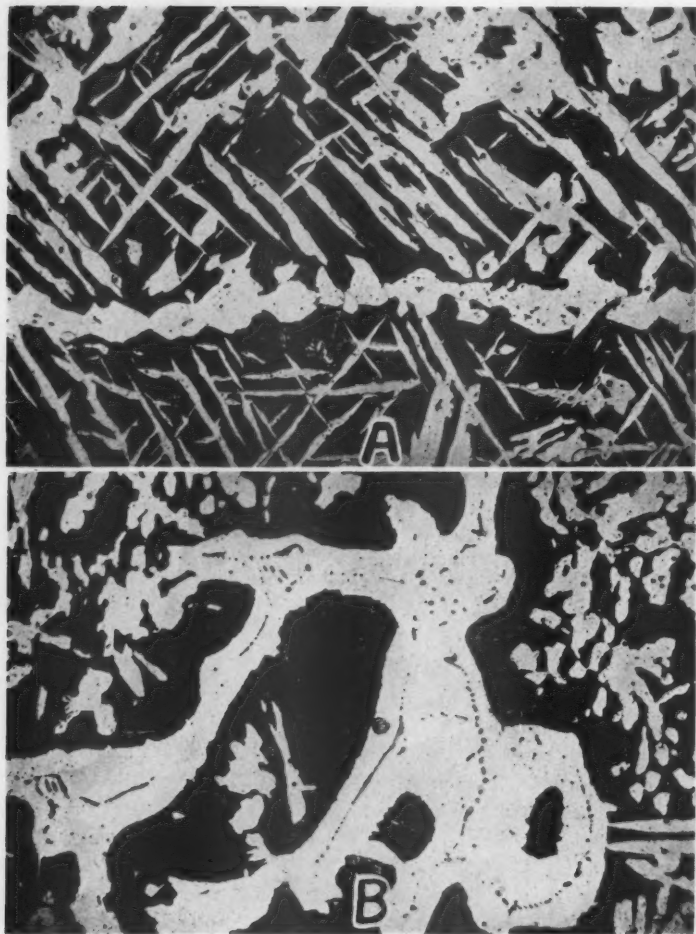


FIG. 2—FORM OF SULPHIDES IN SKIN OF INGOT (A) AND CENTER OF INGOT (B).
STEEL DEOXIDIZED WITH MANGANESE, SILICON AND 0.03 PER CENT ALUMINUM.
ETCHED WITH PICRIC ACID. 100 X.

42. If no manganese is present, FeS alone can precipitate; and it is well known that this sulphide is exceedingly soluble in liquid steel. Therefore, it is not precipitated until very high concentrations are reached, and this can occur only when almost all of the steel at any given point has solidified. The sulphur, therefore, would be found as FeS, or as the eutectic of Fe and FeS, entirely in the grain boundaries except for that in solid solution.

43. As the sulphur precipitates at the last moment of crystallization, there is no opportunity for coalescence into globules. The inclusions therefore appear as thin bands surrounding the grains.

44. The difference in the appearance of FeS and MnS-FeS complexes is attributable, therefore, to differences in solubility. If we postulate that additions of aluminum increase the solubility product (per cent Mn times per cent S), or increase the solubility of sulphur for a given manganese content, with the possible formation of aluminum sulphide or complexes with manganese and iron sulphide, we have a ready explanation of the effect of aluminum on the form in which sulphur exists in steel castings.

45. An increase in solubility means that the sulphide will be thrown out of solution later in crystallization, and that the sulphur will necessarily appear in the grain boundaries in very small globules. The volume of mother liquor between crystallites is too small to allow growth of the inclusions by coalescence.

46. Figs 2-A and 2-B are taken from the skin and center of a 12,000-lb. ingot which was cast from steel deoxidized with manganese, silicon and 0.03 per cent aluminum. The steel analyzed 0.41 per cent C, 0.47 per cent Mn and 0.17 per cent Si. The sulphur in the sample corresponding to Fig. 2-A was 0.028 per cent, and the same sulphur was found in the sample corresponding to Fig. 2-B.

47. In the skin of the ingot, Fig. 2-A, the sulphide distribution is quite similar to Fig. 1-A, even though aluminum has been used. At the center of the ingot, Fig. 2-B, the sulphides are precipitated as tiny globules directly in the grain boundaries, showing that there had not been sufficient time between precipitation and complete solidification for coalescence to take place.

48. Sims and Lilliquist⁹ have clearly shown the effect of the type of inclusion on the ductility of steel castings. They attributed

⁹ Sims, C. E. and Lilliquist, G. A., "Inclusions, Their Effect, Solubility and Control in Cast Steel;" A. I. M. E. *Tech. Pub. No. 453*, advance reprint for Feb. 1932 meeting.

the dispersion of particles in cast steel to lack of FeO and MnO in the metal.

49. Although this may be true to some extent, it is improbable that the small variations in FeO due to an addition of 0.03 per cent aluminum would change the solubility of sulphides to the marked extent shown in Figs. 1-B and 2-B. Variations of from 0.06 to 0.20 per cent silicon and higher, with an attendant decrease in FeO in the metal, have no effect on the form of the sulphides.

50. Unquestionably there are variables other than the form of the inclusion which affect the physical properties. For example, the amount and composition of the ferrite in a normalized test control certain physical properties such as impact strength.

51. From the above considerations it is obvious that if the aluminum must be used to insure sound castings, only two courses can be followed to eliminate the sulphide films resulting from its use:

(a) The manganese content may be made so high that, in spite of the increased solubility of the product, the sulphur is precipitated as small globules with sufficient time and space for coalescence to take place. This course would require such high manganese contents that the physical properties of the metal would be quite different from present-day castings; and, more important still, the cost would be enormous.

(b) If the sulphur content of the steel could be lowered sufficiently, no sulphide envelopes would be found after deoxidation with aluminum. This method would appear to be quite feasible.

52. Elliott¹⁰ has shown that pig iron may be desulphurized rapidly and completely in the basic electric furnace. The desulphurization of the pig iron in a steel casting plant with rotation of a considerable proportion of its own scrap would soon result in castings containing not more than 0.012 per cent sulphur, and this should be sufficiently low to entirely prevent sulphide envelopes around the grains even though aluminum was used in the castings.

53. At the present time, the metallurgical advisory board to

¹⁰ *Foundry*, Sept. 15, 1921, vol. 49, p. 714.

the Carnegie Institute of Technology is investigating the economics of pig iron desulphurization. A low-sulphur steel combined with the best practice in slag control and deoxidation should enable the steel foundryman to produce a product of superior and more uniform physical properties.

DISCUSSION

WRITTEN DISCUSSION

C. E. SIMS¹ and G. A. LILLQUIST:¹ In discussing this paper, we shall be constrained to refer frequently to material given in the paper mentioned by the footnote to paragraph 48 of the paper. If apparently unsubstantiated statements appear in this discussion, supporting evidence may be found in the aforementioned publication.*

The first part of the present paper deals with the proposition of removing inclusions from steel by levitation. This will not be discussed except to say that it is not believed to be of any practical importance in obtaining clean steel, because of the solubility in molten steel of most of the inclusion-forming materials.

Referring to paragraph 32:† Aluminum silicate and Al_2O_3 , sometimes occur accidentally in grain boundaries, but we have never found them around the grains.

Paragraph 33. It is difficult to visualize growing crystals pushing inclusions along ahead of them. Crystals do not grow like a plant by expansion from within, but rather like a snow drift, by additions from without. Moreover, our concepts of physical chemistry tell us that foreign particles suspended in a saturated liquid act as nuclei for crystallization. Concentration of silicates at the point of free crystallization might well be due to the concentration of dissolved material in the steel at that particular point.

Paragraph 39. Any quickly frozen piece of steel, such as a splash test, will show only very small particles of both sulphide and silicate. It is believed that both kinds of inclusions are small for the same reason, namely, the rapid precipitation from solution. We have not examined steel from the interior of slowly cooled ingots, but it is quite certain that in the steel from the center of a 15-in. section cast in sand, silicate and not sulphide is the predominant non-metallic present. Specifically, we

¹ American Steel Foundries, East Chicago, Ind.

* Sims, C. E., and Lillquist, G. A., "Inclusions, Their Effect, Solubility and Control in Cast Steel," *A. I. M. E. Tech. Pub. No. 453*, advance reprint for Feb. 1932 meeting.

† Paragraph numbers referred to in this discussion correspond with numbers of paragraphs in the paper beginning on page 444 herein.

have in mind a steel running: C, 0.266 per cent; Mn, 0.77; Si, 0.36; P, 0.029; S, 0.041.

Paragraphs 40, 41, 46 and 47. It is unfortunate that the authors do not see fit to present Figs. 1 and 2 in the unetched condition, because, especially in Figs. 1-A and 2-A, the etching makes the small sulphide and silicate inclusions indistinguishable and obscure. However, on the basis of numerous observations in the past, it can be said with confidence that, with the difference in the distribution of inclusions shown in Figs. 2-A and 2-B, there will be a similar difference in Figs. 1-A and 2-A, but of course on a smaller scale.

Paragraph 49. It is true that variations of silicon from 0.06 to 0.20 per cent have no visible effect on the sulphide. Even silicon contents as high as 0.80 per cent may have no effect. There can be no effect until the solubility is reduced to the point where at least part of the sulphide stays in solution until crystallization is nearly complete. The action of silicon and aluminum on steel cannot be directly compared, as there is apparently little similarity in their effects. For instance, 0.03 per cent aluminum may have an effect that an additional 20 points of silicon will not produce.

In paragraph 44, the increase in the solubility of sulphides after the addition of aluminum was attributed to the possible formation of aluminum sulphide or complexes with manganese and iron sulphides. Aluminum does not always have the same effect. For instance, it is possible to have two steels of almost identical composition made in the same furnace and both having the same amount of aluminum added, one of which has inclusions like those of Fig. 2-A, the other with inclusions like those of Fig. 2-B. On the other hand, it is possible to have inclusions like those in Fig. 2-B in a steel to which no alloys other than manganese and silicon have been added. Steels in the higher ranges of carbon are prone to this formation.

Paragraph 51. Scores of examples examined have proven that 1.75 per cent manganese is not sufficient to prevent the formation of the wrong type of inclusion when aluminum is used.

Paragraph 52. If it were necessary to practically eliminate sulphur from steel in order to produce sound, ductile castings in green sand, the steel foundries would indeed be in a serious plight. Many thousands of tons of such castings have been made with normal sulphur content. Some steel foundries have no electric furnaces, and most of those that do have them, prefer to run acid process steel. The situation is not so desperate, and we contend that there are ways of using aluminum that will not produce the eutectic type of inclusion with its resultant low ductility. This is not said in defense of sulphur, for we believe it is well to keep sulphur at the lowest practical content.

(Discussion continued on next page)

WRITTEN DISCUSSION

R. C. GOOD:² Congratulations are in order for the preparation and presentation of a paper that covers so much ground in such a brief manner. However, several statements are made that are not confirmed by the writer's experience, and the following comments thereon are respectfully submitted.

We learn, in paragraph 4, that only 60 per cent of the silicates originally contained in the charge are lost before deoxidation. Since about 40 per cent of the metal charged in a basic furnace is pig iron, the open-hearth operator works under a serious handicap if this part of the charge is not produced without due consideration for the impurities it contains.

Unless otherwise informed, paragraph 9 would have us believe that control of the speed of melting lies within the ability of the furnace helper. However, such is not the case, and where furnaces are old and sluggish, this form of FeO control is limited. Under these latter conditions the silicon in the pig iron or balance of the charge should be increased.

The advantage of combination alloys, particularly those with a 4 or 5 to 1 ratio of manganese and silicon, for deoxidation of the steel in the furnace has been demonstrated so thoroughly that everyone should be familiar with the practice. However, it is the belief of the writer that any lime or dolomite should be added ahead of the alloy addition rather than after it. Experience with these alloys on several heats soon will show if any extra lime is necessary. In the production of average steel castings no ladle additions of manganese are necessary when combination alloys of the proper composition are used, and paragraph 26 should be limited to ferrosilicon.

Serious exception is taken to the merits of the scheme proposed in paragraphs 29 and 30 for the introduction of silicon from the slag, especially in the operation of acid electric furnaces, on the basis that steel made in this way will not show as good ductility as steel made with added silicon. A low iron oxide in the slag can easily be obtained with additions of limestone and crushed ferromanganese after the carbon has been suitably lowered, without reducing silicon. It is our firm belief that the best results, from the standpoint of ductility and uniformity, will be obtained in steel from which practically all of the silicon has been oxidized first, then increased before tapping with cold additions. Reduced silicon has a strong tendency to cause the inclusions to appear at the grain boundaries, particularly Al_2O_3 , when aluminum is added to the ladle. No explanation is offered for this phenomenon, but it is believed that the gas-absorbing power of reduced silicon is the principal cause.

Paragraphs 44 to 51 include no recognition of the comparative affinities of aluminum and manganese for oxygen and sulphur. Both of these elements will unite with oxygen in preference to sulphur, so that if we consider that any manganese in excess of that combined with oxygen is

² Electro Metallurgical Sales Corp., Pittsburgh.

free to unite with sulphur, a better explanation of the appearance of the inclusions in the illustrations is available. It also seems reasonable to expect more fluidity in a complex inclusion of oxides and sulphides than in one of sulphides alone. Aluminum-treated steels do not ordinarily show large inclusions that were coalesced during solidification, because aluminum usually is added as an individual element that exerts a strong reducing influence on most of the other oxides, with the result that the products of the reactions have high rather than low fusion points.

Joint Cost Conference*

A. E. GROVER:¹ There is only one type of costs on which a selling price can be established that will guarantee staying in business during periods of high and low production, which we are bound to have from now on as in the past. Those costs are standard costs, or costs as they should be instead of as they are too frequently. This discussion deals exclusively with costs as they should be, with the foundry operating at normal.

Figures presented herewith are from actual experience. We were furnished with ten examples of castings, including heavy jobs, light jobs, hard jobs and easy jobs. The cost system of the plant furnishing these examples has been in operation six years.

A great deal of effort has been spent on costs in this plant, and the system in use shows all the necessary cost facts. Thus, this particular plant was selected because its figures were dependable. Also, the year 1928 was chosen because it represented, of the six years that the system has been in operation, the nearest to a normal year.

Every gray iron foundry contains four basic departments, namely, melting, core making, molding, and cleaning. In the cost system under discussion the cleaning department is divided into two classes, milling and snagging, as charted in Fig. 1.

Across the bottom of this chart, methods of costing are indicated. The first method, shown in column *A*, represents the cost method of the Gray Iron Institute, which I believe is the nearest to a correct cost method in the foundry industry today.

Column *B* represents the tonnage basis method of figuring costs. Column *C* indicates the inclusion of all core cost in molding overhead. Column *D* represents the treating of melting on a tonnage basis and core making on a direct basis, but with milling and snagging included in molding overhead. Method *E* represents

* Joint cost conference between American Foundrymen's Association and Gray Iron Institute, held at 1932 annual A. F. A. convention at Detroit. Discussion was led by A. E. Grover.

¹ Cost Consultant; Director of Costs, Gray Iron Institute, Cleveland.

those companies that include core making, milling and snagging in molding expense.

Column *F* is probably the most debatable method of the six shown in Fig. 1. It provides for costing all cleaning on a straight tonnage basis. The recommendation of the Gray Iron Institute cost manual is to measure all the costs on the various castings, where there is variance enough to pay for the measurement. Every thinking foundryman knows there are certain castings that take more time to clean than other castings, in proportion to tonnage.

It is misleading to combine cleaning or core cost with molding overhead, because there is absolutely no relation between those costs, as will be demonstrated. The method of charging the cost sheet with melting cost at tonnage, core making at direct cost, molding at direct cost, and milling and snagging on a tonnage basis, is just as unreliable as including cleaning in molding overhead.

In Fig. 1, the black lines running from each department to

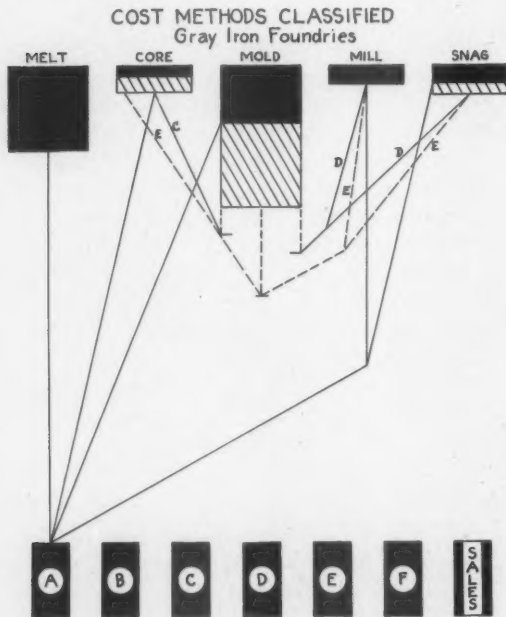


FIG. 1—CLASSIFICATION OF COST METHODS.

column *A* indicate the flow of the costs of these separate departments by the Institute method of direct application.

The solid black portion of "Core" represents direct labor, and the shaded portion represents burden or overhead expense. The solid black portion of "Mold" represents direct labor, and the shaded portion the burden based on the recommended methods in the cost manual of the Gray Iron Institute.

The solid line *C* running from "Core" to "Mold" indicates the additional amount of burden in the molding department by including the total core-making cost. The solid lines *D* running from "Mill" and "Snag" to "Mold," indicate the additional amount of burden in the molding department by including all cleaning cost. The dotted lines *E* running from "Core," "Mill" and "Snag," indicate the additional amount of burden in the molding department by including all core and cleaning costs.

The black portion of "Snag" represents direct labor, and the shaded portion represents burden. The sizes of the black and shaded portions of "Core," "Mold" and "Snag" departments represent the ratio of each to the total cost of the departments.

Costs on the first job of the seven are charted in Fig. 2. This casting weighed 340 lbs. and was cored. Figured by the Gray Iron Institute method, the metal cost of the job is \$469 for the complete order of 102 castings. The core-making cost is \$178 for both labor and burden. The combined molding labor and burden is \$442. This casting was so large that it was not put into the tumbler; the blank column on the chart so indicates. The hand-cleaning cost is \$108 (both labor and burden).

The total of these operation costs are represented by the bar in column *A* of the comparisons section of the chart. These castings were made under normal conditions, so it is the cost of the job as it should be.

The foundryman cannot know whether his competitor will figure his costs in the same way or not, but he can say that his costs are as they should be and then establish a market price according to his individual profit ideals. In this particular case it probably is true that the selling price would somewhat resemble the bar indicated in column *S*. In other words, a profitable market is being established. Perhaps the amount shown cannot be obtained; on the other hand, good salesmen might get more than the selling price indicated. However, it is with this figure that the foundry meets competition.

What about foundrymen who figure costs on a tonnage basis? This being a good-sized casting (340 lbs.), suppose the cost is \$1800, as represented by the bar in column *B*. How is a foundryman to use that high a cost against a market price of \$1330, as shown in column *S*, and still do business?

The man with the Gray Iron Institute method of costing will take the job and make money, whereas a falsified cost will cause another man to refuse it.

Another foundryman, indicated by *C* on the chart of Fig. 2, puts his core-making cost into his molding overhead, treating all

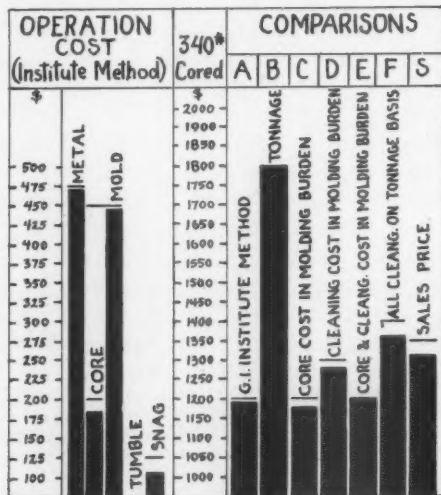


FIG. 2—COST ANALYSIS OF LARGE CORED CASTING JOB.

the rest of the operations in accordance with the Institute method. This cost is quite close to the Institute figure because the core making is a small part of the total cost of this job.

The next man, indicated by *D*, is one who puts his milling and snagging costs into molding overhead. Note the variance from the figure in column *A*.

Class *E* represents the foundryman who puts both core making and milling into his molding overhead. Class *F* represents the foundryman who treats his melting, core and molding costs departmentally, as they should be, but charges his milling and snagging into his job cost on a tonnage basis.

Thus, Fig. 2 gives results from six different cost methods which vary so much that three of them (*B*, *D* and *F*) are each very dangerous to the health of the profit situation of both the individual foundryman using these methods and to the industry as a whole. Bear in mind that these calculations were made from actual performance records in a jobbing foundry.

MEMBER: Is this supposed to be a lot of castings?

A. E. GROVER: It is an individual job of 102 castings in one lot. We did not break the figure down to one casting because we wanted to get a better view of the entire order as it came in.

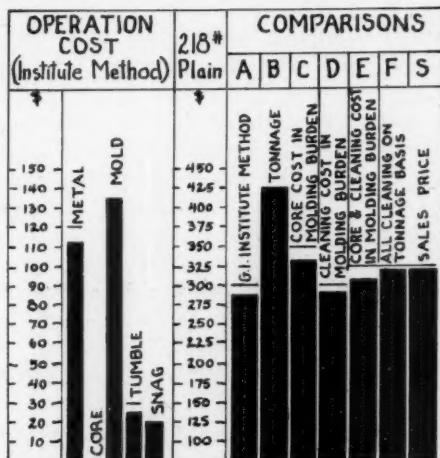


FIG. 3—COST ANALYSIS OF PLAIN CASTING JOB.

CHAIRMAN A. E. HAGEBOECK:² In figuring by the Gray Iron Institute system, which method of handling the cleaning room was taken?

A. E. GROVER: We took the labor cost of actual time on this particular job, plus the overhead at the rate of the snagging department. The casting was not tumbled, so no cost for that operation is shown in the illustration. However, we treat milling (tumbling) on a tonnage basis because it has been our experience that this method gets close to the cost of such castings as one can get into a tumbling machine, and the variance is hardly worth the additional cost to obtain it. However, in some foundries it is

practical to get individual casting costs on tumbling.

Consider another type of casting, the costs on which are charted in Fig. 3. This casting weighs 218 lbs. and the operation costs are:

Metal	\$112
Core	0.00
Mold	133
Tumble	26
Snag	20
<hr/>	
Total.....	\$291

This casting is above the average weight of castings produced. Thus, the tonnage method *B* shows a cost much higher than the operation-measured method recommended by the Gray Iron Institute (column *A*).

The high showing in method *C* is due to the inclusion of the average core cost of all cored jobs in the foundry. Note that this job has no core work, yet the foundryman using method *C* would be very apt to quote a price too high to secure the business. Thus, unconsciously, he would turn away work that would actually return a profit if his costs showed true facts.

There is a close relationship between the average cleaning and molding labor costs of some of the castings produced in the jobbing foundry. The casting of Fig. 3 falls into this class; therefore, the cost by method *D* is very close to the reliable method *A* recommended by the Institute.

Costs shown by methods *E* and *F* are not greatly out of line, yet anyone accustomed to figuring closely the price of castings will agree that even the variations shown are radical enough to be noticed.

CHAIRMAN A. E. HAGEBOECK: Is not method *D* more similar to the Institute standard than any of the other methods shown?

A. E. GROVER: It is closer in this particular instance.

Method *A* is broken down departmentally, as will be shown later, with every department carrying its own labor and burden, as it should. To obtain the basis for costing by method *B* we took the entire cost for the year (metal, labor and burden) and divided by the tonnage of good castings produced, which gave a cost of \$5.12 per hundred pounds of castings. The foundry in question makes castings varying in weight from seven-tenths pound to two tons.

In setting up a basis for calculating costs of the seven jobs being considered, by method *C* (including all core costs in molding burden), we simply added the entire cost of the core department for the year to the molding burden. We then divided the total thus obtained by the molding direct labor for the same period, resulting in a rate of burden to apply to the individual jobs.

In this particular case the job has no cores, but the foundry charges cores into it through molding overhead.

We followed the same procedure in setting up a basis for

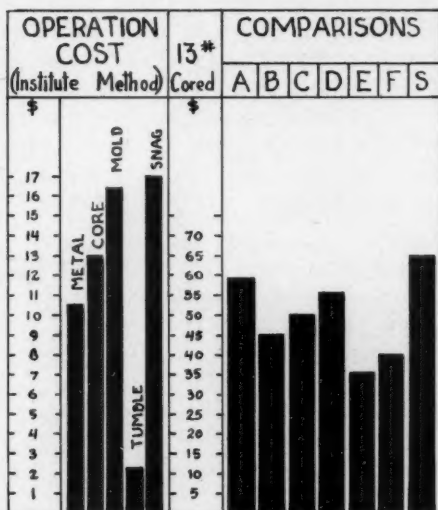


FIG. 4—COST ANALYSIS OF LIGHT CORED CASTING JOB.

method *D* as was used for method *C*, adding the cleaning cost for the year to the molding burden but treating core cost as a direct charge to each casting.

MEMBER: Method *D* takes all cleaning costs into molding overhead, and distributes it by what method?

A. E. GROVER: It is distributed by the direct molding labor method into molding cost. We do not know the author of this method but it is very dangerous, although in common use.

We used the same procedure for setting the basis for costs in method *E* as in method *C*, adding the core and cleaning costs for the year to the molding burden.

In method *F* all core-making cost is charged directly to the job, and molding cost is charged directly to the job, but all cleaning cost is charged on a tonnage basis, in costing every job. No matter what the casting weighs or what its shape is, it costs so much per pound to clean it. We divided the entire cleaning cost for the year by the tonnage of good castings for the same period to get the tonnage rate for costing the seven jobs under discussion.

As to the effect of different methods of costing on a little lighter casting, consider a casting weighing 13 lbs., costs on which are charted in Fig. 4. The operation costs are:

Metal	\$10.53
Core	13.00
Mold	16.57
Tumble	2.42
Snag	17.11
<hr/>	
Total.....	\$59.63

This casting requires much above the average core cost per pound of good castings. This excess core cost over the average is distributed over other jobs (some without any actual core work) where the foundryman uses method *C*. The effect of this method is clearly illustrated by the shortened bar in column *C*.

Note that the snagging cost on this casting is more than the molding cost. The foundryman who uses method *D* distributes a large part of the real snagging cost to other jobs. The measure of this inaccuracy in costing is clearly illustrated by the shortened bar in column *D*.

The other comparisons, columns *E* and *F*, show the effects of core and cleaning, both being larger on this casting than the yearly average.

What are foundrymen who use methods *B*, *C*, *D*, *E* and *F* doing to the industry? Of course, one could say that a foundryman is breaking himself by taking jobs at a loss; but it sometimes takes a long while to break a man in the foundry game. One man I know has been in foundry work for forty years and is not broke yet, although he has never made a cent of profit.

At this point I would like to ask one question. Can anyone in this room conscientiously say that cost accounting is purely a clerk's job and that we have already devoted quite enough attention to it? My own thought is that five years from today the cost man is going to sit at the right hand of the president or

general manager and be just as important to the company as the sales manager. It is the cost man, if he is the right kind, who measures the ability of a business to make profits.

Where are you to get such a man? First of all, you will have to pay for him. There are plenty of men available today, but they cannot be had for fifty or a hundred dollars per month. We may have to educate them. The National Association of Cost Accountants is doing a wonderful work today in educating men to more intelligent cost accounting—men who see the business as it is, men just as capable of seeing the financial conditions of the business as the managers themselves.

CHAIRMAN A. E. HAGEBOECK: I wish to say for the Gray Iron Institute that we had an agreement of the committee on every department set-up except the cleaning department. There we had a definite struggle, and finally we gave our members the option

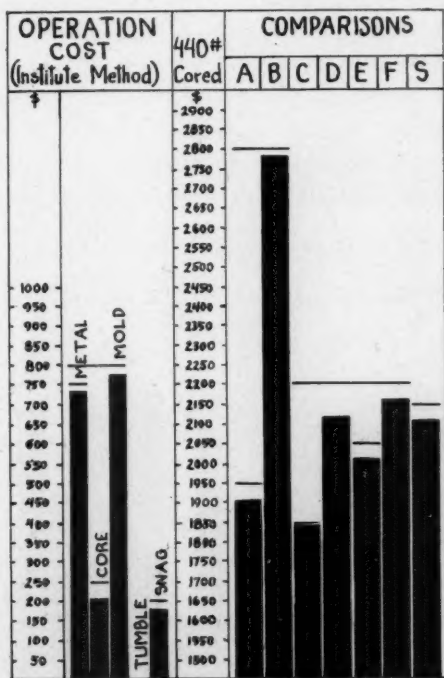


FIG. 5—COST ANALYSIS OF LARGE, HEAVY CORED CASTING JOB.

of using in their cleaning room either the method of figuring the direct cleaning cost on each item and adding the cleaning room burden to it (that was the recommended method), or the alternative of adding the cleaning room cost to molding burden.

MEMBER: To satisfy certain Institute members, the *F* method is included in the Institute's cost manual.

CHAIRMAN A. E. HAGEBOECK: Some wanted to put all their cleaning room costs on a pound basis, which follows the *F* method.

A. E. GROVER: Consider next a large, heavy casting, comparatively easy to make, weighing 440 lbs., costs on which are charted in Fig. 5. Notice how the straight tonnage cost mounts up, and the fluctuation of costs by the other methods. The methods shown, except for *A*, all are faulty; they are misleading to the management. If I were manager, I would rather have a cost guessed at than to have it come to me based on a wrong method of figuring, because the latter is definitely misleading and would prevent my conducting the business as it should be conducted. I would rather take my chances on a guess.

MEMBER: Is this the foundry of a machine tool company?

A. E. GROVER: No, but they make an assembled machine.

MEMBER: Do they make their castings and buy outside?

A. E. GROVER: Yes, and they farm out some of their own cast-

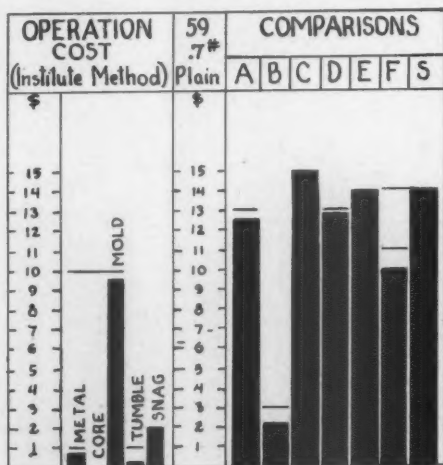


FIG. 6—COST ANALYSIS OF LIGHT PLAIN CASTING JOB.

ings to another foundry that does not know its foundry costs. They also furnish some machine tool castings for a machine tool builder who also does not know foundry costs.

MEMBER: As a general rule, are these patterns gated?

A. E. GROVER: Some are gated, and some are not; I could not tell without referring back to the records.

Let us consider next another type of casting, costs on which are charted in Fig. 6. This casting weighs $\frac{3}{4}$ lb. Note that the metal is not a very large element of cost in this instance. There is a fairly large molding cost and no core cost; a little tumbling and snagging.

MEMBER: How is direct labor figured in cleaning this casting?

A. E. GROVER: We time-study it for cost purposes only. If there were only one casting of that kind, it would not pay to make such a study. However, there are too many such jobs at present.

If anyone present is using a straight tonnage method, think of the absurdity of going out and bidding on the job with the kind of costs shown in *B* of Fig. 6. Do not forget that, even though costs show the figure indicated, the facts (if known) would be as shown in column *A*.

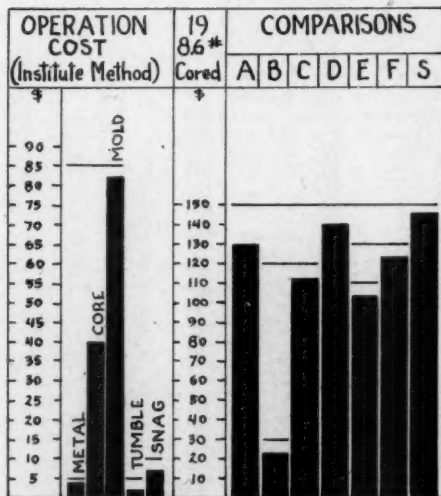


FIG. 7—COST ANALYSIS OF LIGHT CORED CASTING JOB.

Consider next a slightly heavier casting, one weighing 8.6 lbs., costs on which are charted in Fig. 7. Notice the heavy core-making cost, and the very small cleaning cost. The melting cost may seem out of line, but it is due to the number of castings in the order. Again we have a comparatively light casting which shows, on a tonnage basis, a very small figure.

The last of this series of cost comparison charts shows the effect of difficult molding operations on a heavy job. (See Fig. 8.) The operation costs on this job are:

Metal	\$ 554.28
Core	485.98
Mold	1924.22
Tumble	0.00
Snag	457.71
<hr/>	
Total.....	\$3422.19

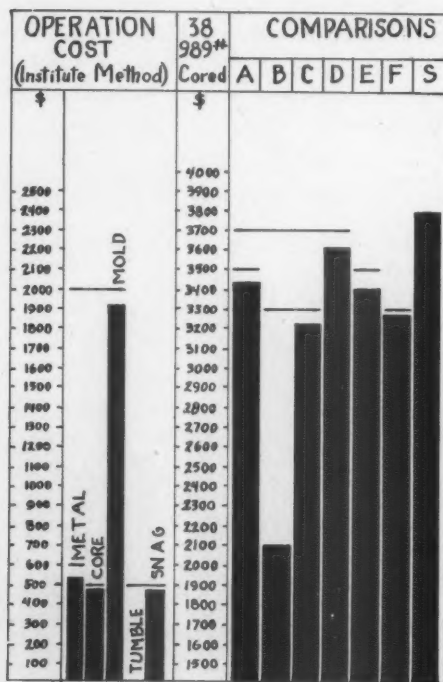


FIG. 8—COST ANALYSIS OF HEAVY CORED CASTING JOB; DIFFICULT MOLDING.

Note the effect on the tonnage cost shown in column *B*. Although the other methods show closer figures to the complete operation-measurement method, as shown in column *A*, with the exception of *E* they are too incorrect to be of value to management in establishing a sales price with intelligence.

After seeing the irregularities in results by these various methods of costing in the foundry industry, we can draw but one conclusion: Many laws of averages must be discontinued and, in their place, some good straight thinking employed.

Depreciation in Costing Methods

In connection with studying the quarterly cost reports of the Gray Iron Institute, several irregularities in costing methods have come to our attention. One of the first was an irregularity in the basis on which depreciation is figured. Members of the Institute,

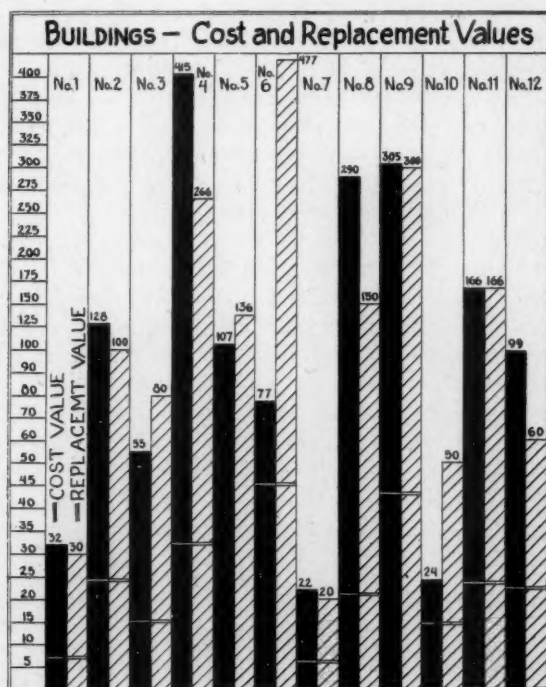


FIG. 9—DEPRECIATION DATA ON FOUNDRY BUILDINGS.

and others in the industry, informed us that the variations in depreciation charges to cost were due largely to the use of fluctuating rates; but none said anything about fluctuations in the values on which the rates were being figured.

All members in the western section received questionnaires asking for the cost figures on buildings and equipment on which depreciation was figured, also for an estimate on what it would cost to replace at present-day values. We received a return of about 75 per cent of the companies reporting cost data, and the data submitted were very helpful. In Fig. 9 a few of the returns are charted to give an idea of the variations in rates and values.

The solid black columns represent the cost values of buildings; the shaded columns represent reproduction values, or the cost to replace at today's values. Notice the variation. Figures at the side represent thousands of dollars.

For example, No. 1 on the chart represents a small company which paid \$32,000 for buildings as they stand on the books. The head of this firm states that he can replace them for \$30,000. No. 2 reports a cost value of \$128,000 and a reproduction value of \$100,000. Notice just the reverse in No. 3: They paid \$55,000 for buildings and state that they would have to pay \$80,000 to replace them. Observe the large plant represented as No. 4: \$415,500 cost and \$266,000 for replacement. Notice also the variations in the rest of the twelve companies charted.

Plant No. 4 perhaps bought buildings at the very highest price of building construction, much higher than would have to be paid today. Is it good business for him to figure depreciation on actual cost in competition with another foundry that figures on today's cost value? If he does, he buries the variance in his cost and wonders why he is not in the market.

There is only one base on which one can profitably establish depreciation, and that is on today's values. If we figure depreciation cost on, say, 1918 values, why not also figure labor cost at the labor rate of 1918? We are selling both to the trade.

MEMBER: Apparently one who has a well-depreciated plant has the advantage.

A. E. GROVER: Do you consider it good business to use that as a club to get orders?

MEMBER: No.

A. E. GROVER: Neither do I.

CHAIRMAN A. E. HAGEBOECK: This is largely a matter of unusual present-day conditions. We have never had two years with such a great difference in costs of building as we have had in 1929 and 1931.

A. E. GROVER: We should act in anticipation of a normal time; find out values for a normal time and use those in establishing prices. The Institute could well afford to make some investigations along this line; it is important.

The chart of Fig. 10 shows equipment worked out on the same basis as buildings in Fig. 9. Notice the fluctuating conditions; here they are even more marked than for building depreciation.

These charts were prepared to show the condition of values used by the industry in figuring costs. Costs should be figured on present-day values of buildings and equipment. We have investi-

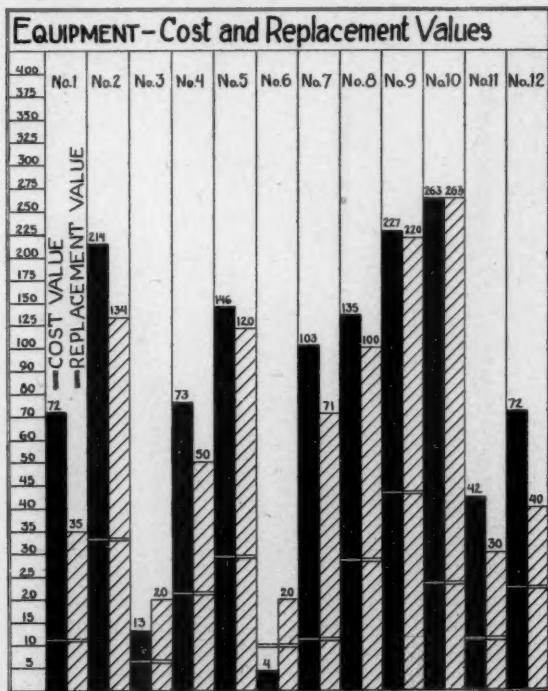


FIG. 10—DEPRECIATION DATA ON FOUNDRY EQUIPMENT.

gated this in the machine tool industry and find there the same condition as in the foundry, only not quite so marked.

To illustrate the depreciation situation a little more plainly, the chart of Fig. 11 has been prepared. The black bars represent present-day values, and 21 companies are represented in the chart. At the right are present-day rates of depreciation being used by this group, the size of the blocks representing the proportion of companies using the rate shown. We heartily agree that foundrymen should use uniform rates, but uniform rates will not answer the question unless we have uniform values back of them on which to figure.

Equipment has been charted along the same lines in Fig. 12, showing the equipment ratios for the same companies, and the equipment depreciation rates in use. In general, these companies are using 10 per cent because the federal government says a firm

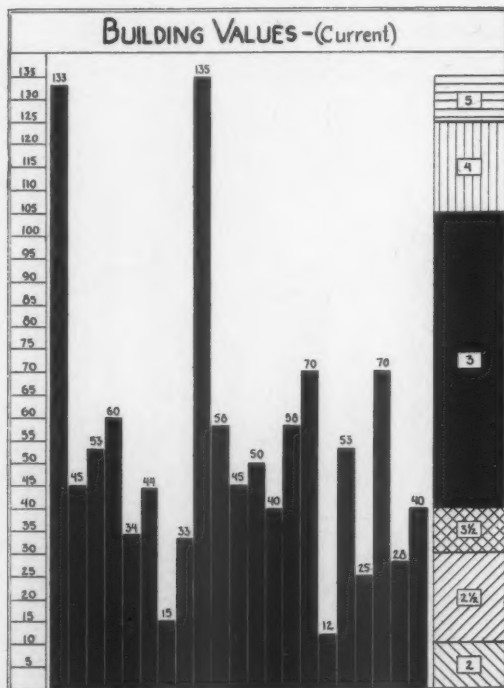


FIG. 11—BUILDING DEPRECIATION RATES USED BY FOUNDRIES.

may take 10 per cent depreciation on its equipment. Perhaps that is good bookkeeping, but it is equally poor cost accounting.

MEMBER: A plant has to take different depreciations if it has sand handling, and the same applies to buildings. One cannot take the same depreciation for a brick building as for an old wooden building.

A. E. GROVER: That is right; we should establish a type of building that is adequate to perform the operation on each different kind of work, and we should standardize on it. My recommendation is to be just as careful of taking an inventory of building and equipment as of stock, and to be just as careful in pricing it. A foundry is selling its buildings and equipment to its customer as much as it sells its metal, coke, labor and all the other things that enter into costs. Therefore, they should all be placed on a correct basis.

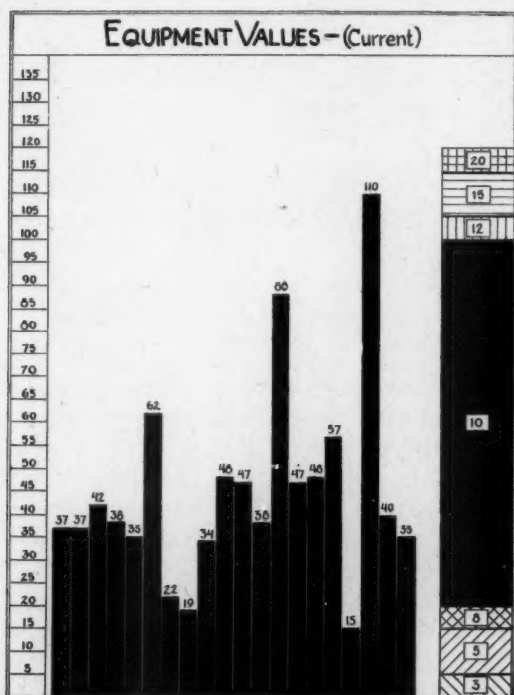


FIG. 12—EQUIPMENT DEPRECIATION RATES USED BY FOUNDRIES.

Fundamentals of Cost Systems

In Fig. 13 the floor plan of a foundry has been sketched. Here the molding department has been divided to show the different classes of work, such as squeezer machines, heavy machines, light floors, etc. In establishing normal costs it is not difficult to obtain them by departments.

Most foundrymen do not find much trouble in segregating the direct labor, but when they come to overhead expense they usually throw up their hands. We have been told there is no such thing as overhead, but I know of no foundry without it. It would

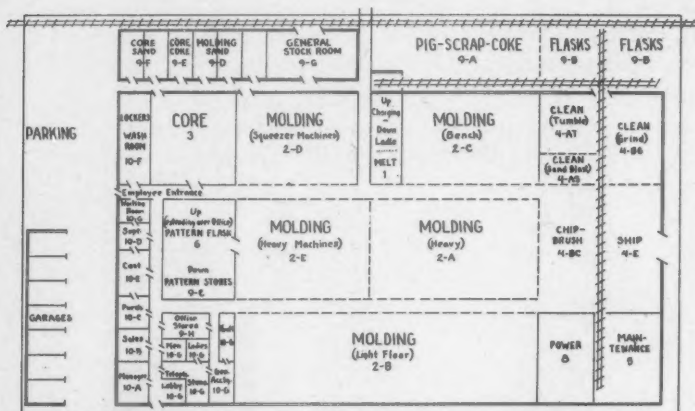


FIG. 13—FLOOR PLAN OF FOUNDRY, WITH WORK CLASSIFIED FOR COSTING PURPOSES.

be fine if we did not have it, because in the foundry it is the largest element of cost. If we could eliminate it we probably could do business at a profit today.

Every cost is caused by producing or selling. Production is divided into metals, labor and burden. Burden is further divided into three classes determined by the three basic methods of distribution.

First, we must furnish a place for the man to work, which we call building expense. Under building expense are included depreciation on buildings, taxes on buildings, insurance on buildings, interest on investment in buildings (if interest is put into the costs), repairs on buildings, lighting and heating of buildings.

These costs go on just the same, or approximately so, whether 500 or 5000 lbs. of castings are made on a particular floor, depending on the shape and size of the casting. Consequently, the job should be charged with these expenses in proportion to the area it occupies.

The second group includes equipment expenses, or tools with which the men work. This group takes in depreciation, taxes, insurance, interest, repairs and power, which are allocated directly to individual departments. Sometimes it is indicated that a molding machine department be further subdivided by individual machines, so that the large heavy machines that cost \$8000 or \$10,000 may carry a larger burden rate than a machine that costs \$300. The foundryman must consider this variance in investment or else he will not get his investment costs back from sales.

Power is charged on the rated horsepower basis; that is, multiply the normal rated horsepower used by the hours used, dividing the power cost to departments and individual machines by the resulting proportion.

Repairs should be kept by departments, which is something not many foundrymen are doing. It costs very little to determine repairs, as they are made, by individual departments. In the machine tool industry we had some plants with forty departments; foundrymen have only five or six basic departments. The machine tool people found it profitable to make that set-up and foundrymen can well do likewise. That is what we call direct application to the department.

The third class is general expense, which fluctuates in departments almost in ratio to the direct labor or direct labor hours. In the ordinary foundry doing about the same type of work, paying the men about the same wages for the work, there is little difference whether direct labor hours or direct labor is used as a basis. We prefer direct labor hours because that basis is always safe. Direct labor has the possibility of increased or decreased wages, which does not increase or decrease any of these expenses in the same ratio. Thus, we must be a little careful of the kind of foundry in which we use direct labor as a base. Direct labor hours are not hard to obtain.

Supervision, clerical, indirect labor, supplies, accident expense, reserve for defective work, and quite a number of other items in the chart of accounts can be distributed in proportion to labor, or what we call the "man basis." It is not right to dis-

tribute them on the basis of floor area or machine valuations. A fictitious and misleading figure would result.

Add the building, equipment and general expense of each department and divide the sum by the normal hours or labor, and a rate will result that is safe to charge into cost.

MEMBER: Where there is a molder and a helper, is a distinction made between the molder and the helper, insofar as the hourly rate is concerned?

A. E. GROVER: That is a good question. If there is a molder and a helper, the molder and helper may or may not use more floor space, and they may or may not use more equipment; they might use more of the general expenses. If it is regular for that molder to have a helper, both should be treated as direct labor on the job; if it is an exception, the helper coming in just to help out, certainly the two should not be added together for burden application, because the regular condition is one man on the job. The fact of using the helper probably did not increase the floor space or equipment and did not increase the supervision on the job, which are the big items of expense.

MEMBER: Referring to your *E* department, suppose one man and an assistant were required to run a \$10,000 machine. Do you set up the price of the machine plus the labor cost to determine a rate for that machine?

A. E. GROVER: We treat the labor and burden separately.

MEMBER: You do not take an hour base if it is on a smaller machine?

A. E. GROVER: If the circumstances warrant, we take the hours and find what each individual machine costs per hour to run it.

MEMBER: Plus the labor?

A. E. GROVER: They can be added together if desired; personally, I prefer them separate.

MEMBER: The printers have a set-up base rate on different styles.

A. E. GROVER: The printers are just forty miles ahead of this industry. Do they use it? They certainly do.

Our industry must come to an analysis of profits if we are going to measure our business as it should be. Fig. 14 presents a

picture of the different activities in the foundry industry today. There are three distinct kinds of profit. Standard profit is the difference between what we sell the products for, and our normal cost to produce them, which we call standard. It can be called either normal or standard.

Another profit is made by the management through good buying of materials, efficient operation of labor, and cutting down unnecessary burden items. Much can be done to accomplish this through comparison of the reports sent in to the Gray Iron Institute.

The third class is the miscellaneous income and expenses that have nothing to do with operation of the plant. Discounts come into this class; that is, cash discounts taken or allowed. Other items are miscellaneous income and expense that have nothing to do with the manufacturing; they are non-operating profits. The sum of the three profit elements gives the net profit.

Under the old method we have been operating, non-operating profit usually has been segregated, but the normal and operating elements are combined so that we do not get a chance to measure whether the sales or manufacturing department made the profit.

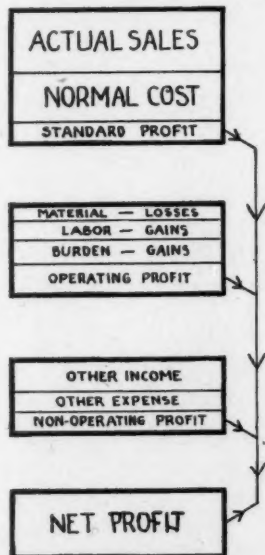


FIG. 14—ANALYSIS OF FOUNDRY PROFITS AND THEIR SOURCES.

In the Institute method we do, because it tells absolutely whether the salesman secured the price he should have received for the job. If he took work at too low a price, he will lessen the standard profit.

Suppose you had an order of castings, the standard cost of which was \$1000 to produce, and your salesman went out with instructions to sell the castings at \$1300 so as to make \$300 profit according to your profit ideal. If he sold them for \$1100 he has given away \$200 worth of profit you should have had. He may have been forced to do it, but in the Institute method at least you have the measurement separated in your profit and loss statement. On the other hand, if you have all the other operating profits buried with it, you cannot measure it.

Suppose, again, that through good management you reduce your cost and actually produce the castings for \$800; you have made a \$200 profit, offsetting the \$200 loss made by the salesman. By this method you would measure both the loss by the salesman and the profit of the shop. The Gray Iron Institute cost system will produce the necessary data to make up this type of profit and loss report.

Report on Recommendations for Cupola Operation*

I—LINING

(A) For lining up a new cupola or relining an old one, a good grade of cupola block or brick of proper dimensions should be used.¹ The block should be laid up with close joints and filled between with a fireclay mixture. Various mixtures² are used.

(B) The shape of lining depends on practice and may be classified under two types, as follows:

(1) Straight side; that is, straight from bottom doors to charging door.

(2) Boshed; that is, a 3 to 6 inch projection at top of tuyeres and tapering off to straight side just above melting zone.

(C) After each heat, chip out badly burned brick and patch with new brick, either split or full size, maintaining the original outlines as closely as possible.

(D) A new breast brick or tap hole should be used if previous one has become too large for the desired flow of molten metal from the cupola.

A tape hole should be about one inch in diameter at the shell for intermittent tapping and should not be over 2 or 3 inches in length.³ For continuous operation, the size should be adjusted to the melting rate. Its location is just at the level of the sand bottom.

* This report is a revision of the committee's report "*Recommended Practice in Operating a 54-Inch Cupola*," published in A. F. A. TRANSACTIONS AND BULLETIN, v. 2, no. 6, June 1931, pp. 49-52, and reprinted in TRANSACTIONS A. F. A. (1931), v. 39, pp. 49-52.

¹ It is economical practice to install several courses of cast-iron brick just below the charging door.

² No detailed information on this point is given because it is expected that it will be fully covered in a report to be presented by the Subcommittee on Foundry Refractories.

³ A short tap hole is used to overcome the risk of freezing of the metal and consequent difficulty in reopening it.

NOTE: This report was presented, discussed and approved before one of the sessions at the 1932 Convention of the American Foundrymen's Association.

(E) The slag hole should be located from 3 to 4 inches below the bottom of the tuyeres. Its size depends on the thickness of the lining and on the size of the cupola. It is usually from 1 to 2 inches either round or square.⁴

II—TUYERES

The area of tuyeres should be approximately one-fourth to one-fifth of the area of the cupola at the level of the tuyeres, the area of the tuyeres to be measured inside the lining. The vertical distance from the center of the sand bottom to the bottom edge of the lower tuyeres should be from 10 to 20 inches, depending on the amount of iron required at one tap. The tuyeres should be as nearly continuous as possible, with a vertical opening 3 to 5 inches in height. For ordinary conditions, use only one row of tuyeres.⁵

III—BOTTOM

(A) The bottom doors should be securely propped and be rigid to eliminate the possible cracking of the sand bottom which would cause a run out.

(B) The bottom sand should be carefully rammed and should slope from all directions toward the tap hole. The sand used should be a rich heap sand free from metallic particles and at the same temper as for molding. All new sand should not be used. The bottom should be about 5 to 6 inches thick at the tap hole, with a uniform pitch toward the tap hole sufficient to allow the iron to flow freely.

IV—LIGHT UP

(A) Slabs of wood are laid flat on the bottom for protection while charging heavier wood. The wood usually is ignited through

⁴The slag hole should be funnel-shaped on the inner end, and also should be as short as possible to prevent freezing, especially in intermittent operation.

⁵When the tuyere area is too small, the velocity of the air will be increased and, while the penetration will be good, the bed will be cooled too much at the tuyeres. The power required to operate the blower also will be increased unnecessarily. If the tuyeres are too large, the velocity will be decreased and the penetration will suffer, thus preventing the coke in the center of the bed from being burned and giving rise to a cone of unconsumed coke. The proper proportions of the tuyeres have been worked out by cupola designers and, in general, the operator has to give this matter little attention. However, he should know the probable effect of the various sizes on the combustion of the coke.

the tuyeres, which are left open to provide draft, or better, by igniting oil-soaked rags and dropping them on the wood bottom from the charging door, then adding sufficient wood to ignite the coke thoroughly. About two-thirds to three-fourths of the coke used on the bed is then added and allowed to burn until the bed is cherry red throughout. The wood used for ignition must be completely burnt out in order that the coke bed be perfectly uniform. The remainder of the coke is then added and leveled off ready for the charging operation.

It is also good practice to use an oil torch or a gas burner instead of wood. The only precaution to be observed is to channel the coke properly so an evenly burned bed will be attained.⁶

(B) The proper height of the coke bed depends upon the character of the iron charge, the disposition to be made of the first iron, the design of the tuyeres, the size and quality of the coke, and the volume and distribution of the blast. The height of the bed can best be determined by the method of trial and error, the time necessary for the appearance of iron of proper quality at the tap hole being the controlling factor. This ordinarily requires from 8 to 10 minutes.

In starting a new cupola, a bed height of 40 to 45 inches above the tuyere may be used safely. If the time is in excess of 8 to 10 minutes, the bed is too high and on the next run the bed should be slightly reduced. This is repeated until the correct height is found. The upper edge of the melting zone is easily determined by examination of the lining after the first heat. A measuring rod should always be used to determine the height of the bed coke. A good bed of ample height is insurance against trouble.

V—CHARGES AND CHARGING

(A) The weight of the iron charge depends upon the size of the cupola. It is sometimes stated that the iron should melt at approximately the rate of 10 lbs. per square inch of cupola area at the tuyeres per hour. The area of a 54-inch cupola, for instance, is 2290 sq. in. Therefore, it would be expected that approximately

⁶ When lighting cupola with torch, build a channel of coke from the breast to the back of cupola and channels from this leading to the sides; this allows the coke bed to burn through evenly. Charge three-fourths of the bed coke; then insert torch through breast and burn until first charge of coke is burned through evenly. The torch is then removed and the breast is made.

11 tons of iron per hour would be melted. This output is considered to be normal for the 54-inch cupola. In order to melt the iron, about 2200 lbs. of coke would be required and, allowing for ten charges per hour, it is found that the individual charge will be about 2000 lbs. and that 200 lbs. of coke will be necessary for the intermediate charges. Similar calculations can be made to determine the charges for a cupola of any size. A suggested curve is given in Fig. 1.

The distribution of the constituents of the iron charge should be so managed that they will all melt at about the same time and thus insure uniform composition. The ordinary charge is made

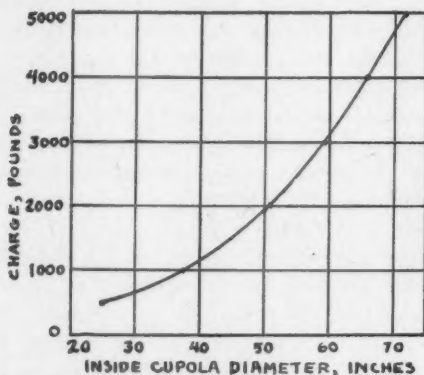


FIG. 1—CURVE TO DETERMINE NORMAL MELTING RATES OF CUPOLAS.

up of pig iron, scrap (either domestic or foreign) and steel. The melting points of pig iron and scrap are about the same, but the pig iron usually is more compact and therefore requires somewhat more time for melting. The steel has a considerably higher melting point. Since the top of the coke bed is the hottest part of the melting zone, the steel and larger pieces of scrap should be charged first to get the benefit of the maximum heat available.⁷ The pig iron, which requires a lower temperature but more time, should be charged next, and finally the scrap should be charged. It is recommended that, so far as possible, the scrap be sized so

⁷ When melting "all-steel" charges, it is advisable to charge part of the ferromanganese, the ferrosilicon and the scrap with the first portion of the steel charge.

that it is in pieces roughly no larger than those of the pig iron. Each constituent should be spread uniformly in its own layer.

(B) Since the combustion of the coke produces the heat required for melting the iron, the amount used depends on the quantity of iron it is desired to melt and the type of charge. For instance, a greater amount of coke is necessary to melt all-steel charges than for soft gray-iron charges. Also, when it is desired to melt at a high temperature, a greater amount of heat is necessary and therefore more coke is required. The quality of the coke, that is, its carbon content, also enters into consideration. It is obvious that a greater weight of coke containing 85 per cent carbon will be required than of coke containing 90 per cent carbon.

The choice of the weight of coke to be used, therefore, is a matter for the cupola operator to consider carefully. It may be stated that ordinarily one pound of coke containing 90 per cent carbon will melt 10 lbs. of iron, giving a ratio of 10 to 1, but ratios as widely different as 6.5 to 1 and 16 to 1 are known to be successfully used. It is considered that the use of an 8 to 1 ratio is good safe practice, but for certain kinds of charges this might not be sufficient and for others it would not be economical.

In a 54-inch cupola, for instance, where the charge selected is 2000 lbs., 200 to 250 lbs. of coke containing 90 per cent carbon may be recommended for ordinary purposes, but under proper conditions and careful control a charge of iron can be melted with considerably less coke.⁸

⁸ *Sizes and Quality of Coke.* Combustion takes place at the surface of the coke, and therefore it would normally be assumed that more rapid combustion and a higher temperature would be produced when small-size coke is used. Too small coke will cause an increase in pressure which, in turn, will increase the power necessary to force the air into the cupola. Larger size coke causes larger voids, a freer path for the blast air, and a reduction in pressure; the possibility of oxygen passing through unconsumed thus is increased.

For these reasons a balance has to be found between the size of the coke and the desired pressure, when the volume supplied remains the same. Incidentally, a higher bed will be necessary when large coke is used in order that the pressure will remain the same, and the coke surface exposed to the action of the oxygen is to be kept constant. For ordinary operations, coke of 4 to 6 inch size is considered best. The coke should be screened to eliminate the smaller sizes and coke breeze.

The quality of the coke, based on the ash content and the reactivity, has an effect on the bed height. In order to obtain the desired temperature, a higher bed will be necessary when high-ash coke is used because of the smaller amount of carbon available for combustion. With low ash and high reactivity, a lower bed can be used because, under these conditions, if the bed is too high, the carbon dioxide formed at first will be reduced to carbon monoxide in the higher portions of the bed with lowering of the temperature.

(C) Fluxes are used to eliminate the ash of the coke and the sand and other dirt carried into the cupola with the iron charges. If a flux is not used, the siliceous materials tend to unite with the oxides of iron and form pasty masses which may bung up the cupola. On longer heats a bridge will be formed which not only upsets the operation of the cupola but increases the labor required in setting up the cupola for a new run. When flux is used, a relatively low-melting and free-running slag is produced which permits the iron to melt cleanly and the operation of the cupola to proceed normally.

The most common flux is limestone, which should consist of 90 or 95 per cent of carbonates. This should be in pieces about 2 inches in diameter. From 2 to 4 per cent by weight of the intermediate coke charge is used, but much more will be necessary if the ash is high or the scrap dirty. It should be charged on the coke layer, keeping it at least 6 inches from the lining to avoid possible cutting, and from the beginning of the heat. Many operators add a charge of flux to the coke bed. Some operators do not add flux until the third charge, but this is not to be recommended as the best practice.⁹

VI—BLAST

The volume of blast air, or better, the actual weight of oxygen charged, is the most important consideration in the operation of the cupola. It depends on the desired rate of melting, the coke ratio, and the quality of the coke. Therefore, no definite volume or weight of air can reasonably be specified. Under conditions

⁹ As stated above, the flux, which is basic in reaction, combines with the siliceous or acid substances in the charge to form silicates which at the temperature of the cupola are readily fusible. The silicates of iron have high melting points and form slags which are pasty and difficult to handle.

Fluorspar sometimes is used because of its easy fusibility and its great reactivity, and perhaps because a smaller proportion is sufficient.

Fused soda ash has been found superior to fluorspar as a flux, and often may be used to advantage.

It is generally considered in practice that one pound of coke is required to melt 10 lbs. of iron; therefore, to melt one ton of iron, the carbon available is actually 180 lbs., the carbon content usually being 90 per cent and the air requirement at 60 degs. Fahr., and normal pressure is

$$180 \times 151 = 27,200 \text{ cubic feet.}$$

This figure is based on complete combustion. In very few cases, however, does this condition exist. Some carbon monoxide and oxygen

(Continued on next page)

existing normally over most of the territory in which foundries are located, approximately 151 cu. ft. of air are required to burn 1 pound of carbon completely. Thus, if the weight of coke and its carbon content are accurately known, the required volume of air can be calculated. Corrections for temperature at barometric pressure should be made in extreme cases.⁹

The blast pressure varies according to style and size of tuyere openings, height of stack, and size of coke and metal used in the charge. The pressure may vary from 6 ounces to 24 ounces, depending on the above conditions.

For uniform melting, the volume should be kept constant and the pressure allowed to vary. Every cupola should be equipped with volume and pressure gages and a means of adjusting the amount of air delivered into the wind box.

VII—RECOMMENDATIONS

Any cupola should be operated on a fixed schedule; that is, a definite time for light up, for start of charging, for starting blast, for tapping out, and for opening slag hole. The tap hole should be carefully gaged to promote the desired rate of flow of molten iron, whether continuous or intermittent tapping is used. The blast volume should be maintained uniformly until the heat is nearly finished, and then gradually decreased until the last tap is made.

(Continued from previous page)

usually are found in stack gases, along with the inert nitrogen. Under the usual working conditions, only 60-65 per cent of the carbon is finally burned to carbon dioxide, and 40-35 per cent to carbon monoxide; therefore, the actual weight of oxygen required will be

$$180 \times 0.62 \times 2.67 = 298 \text{ lbs. oxygen for CO}_2 \text{ and}$$

$$180 \times 0.38 \times 1.33 = 91 \text{ lbs. oxygen for CO.}$$

The total oxygen requirement then is 389 lbs. This oxygen is accompanied in the air by nitrogen, which does not burn at all and serves merely to dilute the gases and to increase the amount of heat required. Nitrogen is present in atmospheric air to the extent of 76.9 per cent by weight; therefore, 389 lbs. of oxygen will be accompanied by 1292 lbs. of nitrogen, and the total weight of air will be 1681 lbs. This will occupy, at 60 degs. Fahr. and normal barometric pressure, 22,000 cu. ft. On account of blower slippage, pipe friction and leakage, about 10 per cent should be added, and in order to insure the free access of the proper amount of oxygen to the cupola, a total of 24,200 cu. ft. of air should be supplied.

This figure is based on a 10 to 1 melting ratio based on the coke weight, of which only about 90 per cent is carbon. (Very few cupolas in this country are being operated at anything like this efficiency. In the majority of cases, 8 to 1 melting is considered very satisfactory, and under such circumstances it generally is assumed that 30,000 cu. ft. of air is the requirement for melting one ton of iron.)

All materials used should be checked and recorded daily. In fact, to operate a cupola successfully, adopt a standard practice and stick to it.

Effects of Eleven Metals or Alloys on the Physical Properties of Gray Cast Iron

By W. H. SPENCER* and M. M. WALDING,* BIRMINGHAM, ALA.

Abstract

Because of obtaining unexplained results in the physical properties of iron castings, which the usual chemical tests and melting, molding and other practices followed have not explained, the authors conducted a series of experiments to determine what effects could be attributed to elements sometimes found in scrap iron. The materials added were lead, antimony, tin, bismuth, cadmium, metallic arsenic, ferro-arsenic, copper, Tobin bronze, brass and bearing metal. Two types of cast iron, used as base metals, were melted and the additions made in the ladle. Results on test bars with the alloy additions were compared with test bars made without the alloy additions. The results indicate important effects on the irons, with varying effect on the two types of irons. Detailed analyses and effects on the properties are given in tables and charts.

I—INTRODUCTION

1. In producing gray cast iron there have been many instances when the transverse strength, impact strength, stiffness, hardness and chilling properties have not been the same on two casts which apparently should have had the same physical properties. Studies of the melting conditions, molding, casting and other variables frequently have failed to furnish explanations for the abnormal irons. An ordinary analysis (including silicon, sulphur, manganese, phosphorus and total carbon determinations) was not sufficient in these cases.

2. An example of this abnormality in the physical properties of cast iron, which was one of the causes of this investiga-

*American Cast Iron Pipe Co.

NOTE: This paper was presented and discussed before one of the gray iron sessions at the 1932 Convention of the American Foundrymen's Association.

tion, occurred recently when two heats were made with the results given in Table 1.

3. The melting and casting methods were the same for both heats. The mixtures were the same, except that the scrap used in Heat A included some bearing metal. A spectrographic analysis showed lead and antimony present in Heat A in amounts less than 0.01 per cent. Heat B was free from these metals.

4. The microstructure of the abnormal iron would show, in most cases, the effect but not the cause. Even this means some-

Table 1

	Heat A.	Heat B.
Transverse Breaking Loads, lbs., $2 \times 1 \times 24$ in. test		
bar.....	2080	3050
Ultimate Modulus of Elasticity, lbs. per sq. in. $\times 10^{-6}$.	13.4	13.7
Impact Strength, inches drop.....	7.0	17.0
Brinell Hardness, average.....	251	221
Depth of Chill, inches.....	0.55	0.23
Chemical Analysis:	Per cent.	Per cent.
Silicon	1.97	2.02
Sulphur (gravimetric)	0.089	0.079
Manganese	0.59	0.61
Phosphorus	0.57	0.42
Total Carbon	2.98	3.03
Combined Carbon	1.22	0.77
Graphitic Carbon	1.76	2.26
Titanium	0.04	0.04
Vanadium	0.02	0.01
Copper	0.33	0.12
Tin	0.74	0.00
Arsenic	0.04	0.02
Nickel	0.07	0.01
Chromium	0.00	0.00
Tungsten	0.00	0.00
Molybdenum	0.00	0.00
Spectroscopic Analysis:		
Carbon	above 0.10	above 0.10
Silicon	above 0.10	above 0.10
Manganese	above 0.10	above 0.10
Tin	above 0.10	less 0.01
Copper	above 0.10	above 0.10
Titanium	between 0.01 and 0.10	0.01-0.10
Vanadium	between 0.01 and 0.10	0.01-0.10
Nickel	between 0.01 and 0.10	0.01-0.10
Chromium	trace, less than 0.01	less 0.01
Lead	trace, less than 0.01	absent
Antimony	trace, less than 0.01	absent
Cobalt	trace, less than 0.01	less 0.01
Germanium	trace, less than 0.01	less 0.01
Gallium	trace, less than 0.01	less 0.01
Zinc	trace, less than 0.01	less 0.01

Table 2
EFFECT OF BRASS SCRAP IN NI-RESIST†

Heat.	Mixture.*	Load lbs.	Ult. Mod. Elong., lbs. per sq. in. × 10 ⁻³	Impact Stgth.**	Sl, %	Mn, %	TC, %	Ni, %	Cu, %	Cr, %	Zn, %
1	10% Scrap Ni-Resist	2170	3.5	24.5	2.14	1.45	3.06	13.59	6.24	1.16	0.02
2	20% Monel	1970	2.8	18.0	2.75	1.48	2.97	14.70	5.30	1.08	0.01
3	50% Scrap Ni-Resist	1980	4.5	23.0	1.81	1.64	3.12	12.50	5.00	0.51	0.02
4	20% Monel	1510	2.7	14.0	2.72	1.60	3.10	13.72	5.76	1.22	0.02
5	20% Monel	2020	3.8	18.5	2.73	2.81	3.04	12.25	5.80	1.05	0.02
6	20% Monel	2820	4.5	21.5	2.54	1.12	2.86	16.23	6.04	1.16	0.02
7	20% Monel mixed with Brass	1620	9.3	11.0	1.56	1.50	2.94	13.40	5.14	1.03	0.07
8	13% Scrap Ni-Resist partly from Heat No. 7	2200	9.3	15.0	2.16	0.70	2.95	13.91	7.36	0.99	0.17
9	25% Scrap Ni-Resist partly from Heat No. 7	1450	6.3	10.0	2.55	1.54	2.95	15.48	6.25	1.35	0.05
10	10% Scrap Ni-Resist from Heat No. 9	1240	8.3	8.5	2.30	1.45	2.95	14.03	6.00	1.05	0.09
11	Same as Heat No. 10	1200	8.3	8.0	2.47	1.39	2.96	14.16	5.96	1.00	0.10

* The material listed is the scrap portion of the charge.

† Analyses given are for the iron in the test bars cast from each heat.

** Inches of drop of hammer on the ultimate or breaking blow.

Table 3

Addition.	Form.	Visible Results.
Lead	$\frac{1}{2} \times \frac{3}{4} \times 2$ in.	Small amount of fumes.
Antimony	$\frac{1}{4}$ -lb. Lumps	Practically no fumes.
Tin	$\frac{3}{8}$ -in. Rods	No fumes.
Bismuth	$\frac{1}{4}$ -lb. Lumps	Slight boiling.
Cadmium	Lumps	Series of explosions.
Metallic Arsenic	Granular	Dense fumes.
Ferroarsenic	Lumps	Some fumes and considerable boiling.
Copper	Wire	No action.
Tobin Bronze	Welding Rods	Some blaze and fumes.
Brass	Drillings	Blaze, boiling and fumes.
Bearing Metal	Lumps	Very little action.

times failed to show a difference between an abnormal iron and one having normal properties.

5. Cast iron having unexplained physical properties has been the cause of much discussion. The present investigation was undertaken with the intention of ascertaining the effects of several more or less neglected metals which might be present in cast iron generally because of their inclusion in scrap iron. The metals or alloys used in the tests were lead, antimony, tin, bismuth, cadmium, metallic arsenic, ferroarsenic, copper, Tobin bronze (copper 70 per cent, zinc 30 per cent), brass and white bearing metal.

6. Many of these were known to be present in scrap. Antimony, tin, arsenic and copper are known to be present in varying amounts in commercial pig iron. Bearings and bushings in commercial scrap may contain lead, tin, bismuth, antimony, zinc and copper. Plated or galvanized scrap may furnish tin, cadmium or zinc. Cast-iron scrap, without bearings, bushings or plated material, may have been made from a mixture which did contain such materials.

7. Table 2 shows that zinc affected the physical properties of cast iron after several remelts. During the running of the heats shown in this table, the iron containing zinc gave off heavy fumes when exposed to the air, yet the physical tests still showed the effects of zinc.

8. The irons shown in Table 2 contained from 0.034 to 0.054 per cent sulphur and 0.02 to 0.23 per cent phosphorus. The first six heats were brass free, the seventh heat contained brass, and the last four heats contained scrap which was contaminated with brass. In all cases where zinc was present in amounts over 0.05

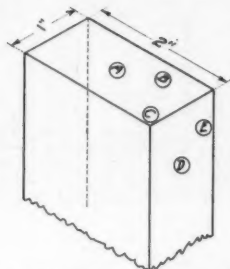


FIG. 1—DIAGRAM SHOWING LOCATION OF BRINELL READINGS ON TEST BARS.

per cent, the stiffness of the iron was increased and the strength—particularly the impact strength—was lowered. All of the Ni-Resist heats were made in the electric furnace.

II—METHODS

9. A 3000-lb. ladle was filled with iron from the cupola. The desired addition of metal was placed in a 150-lb. shank ladle and iron was poured from the larger ladle into the smaller one. A set of three $2 \times 1 \times 26$ in. test bars was cast in dry-sand molds from each shank ladle. Several sets of test bars containing different metal additions, and one set of plain test bars, were poured from each large ladle. The set with no addition was used as a standard for the comparison of other sets.

10. Table 3 gives information in regard to the metals used and the visible results of the addition of the metal to the iron.

11. The pouring temperature of the test bars was determined by means of a Leeds & Northrup optical pyrometer. All test bars were poured at approximately the same temperature.

12. The standard irons were of two distinct classes, referred to herein as No. 1 and No. 2 irons. The metal additions were made in approximately 0.25 per cent and 1 per cent amounts of each metal. This gave four combinations for each metal or alloy added.

Transverse Test.

13. The test bars were broken transversely on 24 in. supports. A Riehle machine was used which gave an autographic record of the load-deflection curve for each bar. The results from the three test bars in each set were averaged after being corrected for bar size. The ultimate load was compared with the ultimate load on the standard bars for that set. The ultimate modulus of

Table 4
CHEMICAL ANALYSES OF BARS

Set.	Test No.	Si, %	S, %	Mn, %	P, %	TC, %	Other Elements, %	Additions.
1	1862	1.00	0.080	0.54	0.73	3.54	Cu 0.86	1% brass.
	1863	1.60	0.075	0.55	0.75	3.56	Zn 0.04	Standard.
	1869	1.89	0.080	0.54	0.68	3.39	Zn 0.02	1% lead.
2	1870	1.88	0.080	0.54	0.66	3.43		Standard.
	1873	1.35	0.101	0.50	0.67	3.41	Sn 0.91	1% blinuth.
	1874	1.37	0.098	0.49	0.68	3.38		1% Tobin bronze.
3	1875	1.39	0.098	0.46	0.68	3.40	Cu 0.53	1% metallic arsenic.
	1882	1.38	0.083	0.40	0.61	3.44	Zn 0.09	1% ferrous arsenic.
	1883	1.22	0.103	0.43	0.64	3.21	Zn 0.01	Standard.
4	1885	1.22	0.103	0.43	0.64	3.21	As 0.29	1% white bearing metal.
	1887	1.24	0.104	0.42	0.63	3.22	As 0.14	Standard.
	1888	1.24	0.104	0.42	0.63	3.22	As 0.05	1% antimony.
5	1893	1.18	0.107	0.45	0.58	3.12	Sb 1.04	Standard.
	1894	1.19	0.113	0.45	0.58	3.16	Cu 0.76	1% copper.
	1895	1.18	0.113	0.45	0.58	3.16	Cu 0.58	1% Tobin bronze.
6	1914	1.25	0.116	0.47	0.62	3.16	Zn 0.15	1% lead.
	1915	1.22	0.113	0.45	0.61	3.16	Zn 0.01	1% cadmium.
	1916	1.24	0.114	0.43	0.58	3.17		0.25% copper.
7	1917	1.11	0.120	0.44	0.57	3.04	Cu 0.36	1% Tobin bronze.
	1918	1.13	0.120			3.03	Cu 0.21	Standard.
	1919	1.12	0.120			3.01	Zn 0.05	1% lead.
8	1920	1.17	0.121			3.04		0.25% cadmium.
	1921	1.14	0.121			3.02		1% Tobin bronze.
	1922	1.21	0.106	0.46	0.57	3.07	Sn 0.32	Standard.
9	1923	1.19	0.114	0.42	0.57	3.08	Sb 0.35	0.25% lead.
	1924	1.19	0.103	0.42	0.58	3.10		0.25% tin.
	1925	1.23	0.103	0.45	0.60	3.19		Standard.
10	1926	1.24	0.099			3.19		0.25% antimony.
	1927	1.24	0.104			3.19		0.25% cadmium.
	1928	1.24	0.104			3.19		84.25% bearing metal.
11	1929	1.18	0.108	0.46	0.59	3.09		0.25% blinuth.
	1930	1.18	0.108	0.42	0.58	3.08	As 0.11	0.25% ferroarsenic.
	1931	1.17	0.110			3.08	As 0.04	Standard.
12	1937	1.71	0.115	0.54	0.60	3.56	Cu 0.34	0.25% copper.
	1938	1.77	0.108			3.55	Cu 0.26	0.25% Tobin bronze.
	1939	1.73	0.108			3.55		0.25% lead.
13	1940	1.72	0.106			3.56	Sn 0.21	0.25% tin.
	1941	1.77	0.106			3.56	Sb 0.22	0.25% antimony.
	1942	1.72	0.103	0.52	0.66	3.57		Standard.

Table 4—Continued

Sef.	Test No.	Si, %	S, %	Mn, %	P, %	TC, %	Other Elements, %	Additions.
13	1943	1.71	0.103	0.52	0.69	3.61		0.25% cadmium.
	1944	1.69	0.103			3.61		0.25% bismuth.
	1945	1.69	0.103			3.59		0.25% bearing metal.
	1946	1.70	0.101			3.57	As 0.05	Standard.
	1947	1.68	0.100			3.57	As 0.16	0.25% metallic arsenic.
14	1948	1.70	0.090	0.53	0.67	3.59	As 0.08	0.25% ferroarsenic.
	1949	1.70	0.090	0.57	0.67	3.54	Sn 0.87	1% tin.
	1950	1.65	0.085			3.52	As 0.06	1% antimony.
	1951	1.70	0.085		0.67	3.56		Standard.
	1952	1.69	0.087			3.54		1% cadmium.
15	1953	1.69	0.084			3.51	Sb 0.74	1% metallic arsenic.
	1954	1.69	0.085	0.56		3.53	As 0.24	1% ferroarsenic.
	1957	1.69	0.089	0.50	0.67	3.39	As 0.17	1% bearing metal.
	1958	1.67	0.087	0.52	0.68	3.44		1% bismuth.
	1959	1.72	0.098			3.46		Standard.
16	1961	1.19	0.097	0.46	0.58	3.25	Cu 0.78	1% brass.
	1962	1.19	0.097			3.25	Cu 0.24	0.25% brass.
	1963	1.21	0.103			3.25	As 0.04	Standard.
	1964	1.21	0.099	0.43	0.59	3.29	As 0.09	0.25% metallic arsenic.
	1965	1.80	0.070	0.60	0.76	3.58	Cu 0.24	0.25% brass.
17	1966	1.82	0.074			3.67	1% copper.	
	1968	1.79	0.073	0.60	0.74	3.65	Cu 0.84	Standard.

elasticity, or stiffness ratio, was calculated from the load-deflection ratio.

Impact Test.

14. After the transverse test, the pieces of the bars were subjected to the impact test. This test was made by means of a 25-lb. hammer falling vertically on the bar. The supports were 6 inches apart. The first drop was made from a height of 8 inches and increased $\frac{1}{2}$ inch on each succeeding drop until fracture occurred, unless the first bar broke at 8 inches; in this case the first drop was made at 4 inches on the remaining bars of that set. The blows were repeated on the same spot, without reversal of the bar.

Hardness.

15. Brinell hardness was determined on the 2×1 in. bar in the center, quarter, and corner of the cross-section, and in the center and quarter of one side (Fig. 1). The average was used in the tables.

Chill.

16. One chill specimen $1\frac{1}{2} \times 1\frac{1}{2} \times 6$ in. and another $1\frac{1}{2} \times 3 \times 6$ in. were cast from each ladle of iron. The chill molds were made in green sand with a $1\frac{1}{2}$ -in. face against a cast-iron chill block. When the chill test was cold it was broken and the depth of chilling measured at one-third points along the face of the specimen. Average readings were employed in the calculations.

17. Chill test results were reported in inches and not in percentages. The difference between the depth of chill on the treated and plain iron is given in the tables.

Chemical Analysis.

18. Chemical analyses were made on samples from the test bars. The analyses for bismuth and lead showed these metals absent even though one per cent had been added and the physical properties had been greatly affected. The methods used detected lead or bismuth mechanically mixed with standard samples. Spectrographic analyses* on the one per cent additions having the most

* Spectrographic analyses made by A. W. Petrey, Aluminum Co. of America.

effect on the physical properties showed lead and bismuth present in amounts less than 0.01 per cent.

Comparison of Properties.

19. Since the bars for the various additions of each metal did not all come from the same ladle of iron, the absolute values for the various physical properties could not be compared. The percentage variation of the bar with addition, from the bar without addition made from the same ladle, was taken as the measure of the effect of the addition. The standard bars were taken as zero variation and the bars which had other metals added were reported as percentage plus or minus, as they exceeded or fell below the standard values for the set.

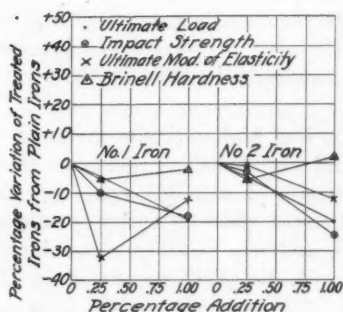


FIG. 2—EFFECTS ON PROPERTIES OF TWO IRONS, WHEN VARIOUS PERCENTAGES OF LEAD ARE ADDED.

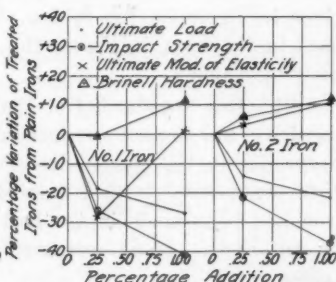


FIG. 3—EFFECTS ON PROPERTIES OF TWO IRONS, WHEN VARIOUS PERCENTAGES OF TIN ARE ADDED.

Table 5

EFFECTS OF LEAD

Test No.	1917	1870	1922	1939*
Base iron	No. 2	No. 1	No. 2	No. 1
Addition, % lead	1	1	0.25	0.25
Deviation of Treated Iron when compared with standards:				
(a) Chill, inches	+ 0.60	— 0.01	+0.12	+ 0.03
(b) Ultimate load, %	—20.1	—19.3	—4.9	— 4.5
(c) Impact strength, %	—25.0	—18.5	—3.0	—10.1
(d) Ultimate modulus, %	—12.9	—12.6	—0.7	—32.6
(e) Brinell No., avg., %	+ 1.8	— 2.3	—4.8	— 4.9

* No. 1939 was compared with standard No. 1942.

Table 6

EFFECTS OF ANTIMONY

Test. No.	1894	1950	1925	1941*
Base iron	No. 2	No. 1	No. 2	No. 1
Addition, % Antimony.....	1	1	0.25	0.25
Deviation of Treated Iron when compared with standards:				
(a) Chill, inches	+ 0.45	+ 0.04	+ 0.43	+ 0.01
(b) Ultimate load, %.....	-52.8	-42.0	-18.3	-21.7
(c) Impact strength, %.....	-66.6	-56.4	-27.7	-33.3
(d) Ultimate modulus, %.....	+ 5.6	-11.1	+ 4.9	-23.6
(e) Brinell No., avg., %.....	+22.5	+ 9.1	+11.5	+ 3.4
Antimony in bars, %.....	1.04	0.74	0.35	0.22

* No. 1941 was compared with standard No. 1942.

20. The results obtained with the various metal additions are given in accompanying tables. The chemical analyses of the bars used in the tests, including the standards, is given in the accompanying Table 4.

21. One standard, No. 1942, had high ultimate modulus of elasticity, low impact strength, and gave fictitious results on these properties to the treated irons compared with it. Standard No. 1942 was poured from a ladle directly after an antimony-treated iron had been made in the ladle, and was possibly contaminated by antimony. Irons compared with No. 1942 are noted in the tables.

SUMMARY

Lead.

22. As shown in Fig. 2, disregarding the ultimate modulus value obtained by comparison with standard No. 1942, consistent results were obtained.

23. The load and impact strength for both base irons with lead were lower than those for the plain irons. Increasing the lead addition reduced the load and impact values in approximately direct proportion.

24. In the case of lead additions, there was a lowering of ultimate modulus and Brinell hardness below those of the standard irons. The chills on No. 2 iron with lead were deeper than those on the plain iron.

Antimony.

25. Fig. 4 shows graphically the results obtained by the addition of antimony to cast iron. In this series there is a comparison of ultimate modulus, with No. 1942 standard.

26. Load and impact strengths were lowered very rapidly by the addition of antimony. The impact strength was affected somewhat more than the load.

27. The ultimate modulus of elasticity was above standard for No. 2 irons and below standard for No. 1 irons. The Brinell hardness was above normal for both No. 1 and No. 2 irons, but highest on No. 2 iron. Antimony gave deep chill with No. 2 iron.

Tin.

28. Fig. 3 gives the values for tin additions. Here again is an ultimate modulus derived from comparison with standard, No. 1942.

29. The load and impact strengths were lowered by tin additions, but increasing the tin content reduced these values only

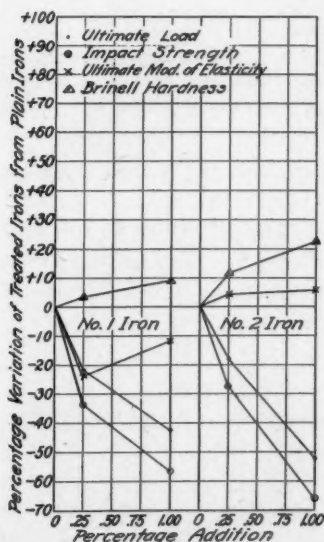


FIG. 4—EFFECTS ON PROPERTIES OF TWO IRONS, WHEN VARIOUS PERCENTAGES OF ANTIMONY ARE ADDED.

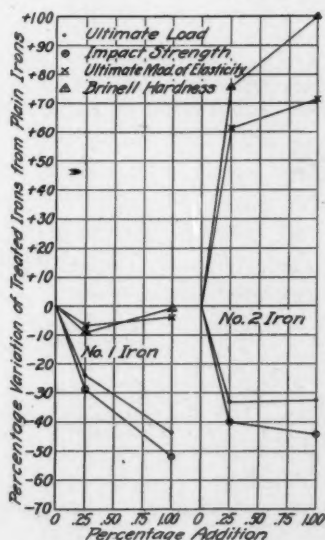


FIG. 5—EFFECTS ON PROPERTIES OF TWO IRONS, WHEN VARIOUS PERCENTAGES OF BISMUTH ARE ADDED.

Table 7

EFFECTS OF TIN

Test No.	1874	1949	1923	1940*
Base iron	No. 2	No. 1	No. 2	No. 1
Addition, % tin.....	1	1	0.25	0.25
Deviation of Treated Iron when compared with standards:				
(a) Chill, inches	No test	+ 0.05	+ 0.23	+ 0.03
(b) Ultimate load, %.....	-21.9	-26.8	-14.5	-18.9
(c) Impact strength, %.....	-37.1	-41.0	-21.4	-26.5
(d) Ultimate modulus, %.....	+10.6	+ 1.8	+ 3.5	-28.2
(e) Brinell No., avg., %.....	+11.7	+11.1	+ 5.7	- 0.5
Tin in test bars, %.....	0.91	0.87	0.32	0.21

* No. 1940 was compared with standard No. 1942.

Table 8

EFFECTS OF BISMUTH

Test No.	1875	1958	1929	1944
Base iron	No. 2	No. 1	No. 2	No. 1
Addition, % bismuth.....	1	1	0.25	0.25
Deviation of Treated Iron when compared with standards:				
(a) Chill, inches	+ 2.82	+ 0.68	+ 2.40	+ 0.55
(b) Ultimate load, %.....	-32.3	-43.1	-32.8	-23.3
(c) Impact strength, %.....	-44.1	-51.5	-39.8	-28.8
(d) Ultimate modulus, %.....	+71.2	- 3.4	+61.8	- 6.6
(e) Brinell No., avg., %.....	+100.0	- 0.9	+75.9	- 9.0

slightly further. The impact was more affected than the load by tin.

30. The ultimate modulus and Brinell hardness increased with tin additions. The hardness with one per cent tin was raised approximately the same amount on both No. 1 and No. 2 irons.

31. Tin gave some increase in chilling effect.

Bismuth.

32. Fig. 5 gives the graph for the variations due to the additions of bismuth.

33. The load and impact strength were both lowered by the addition of bismuth. Increasing bismuth addition reduced still more these values on No. 1 iron, but had little effect on No. 2 iron.

34. The ultimate modulus and hardness on No. 2 irons were far above normal with the presence of bismuth. The No. 1 irons,

however, showed ultimate modulus and hardness below standard, for the same addition of bismuth.

35. The chilling effect on both irons was greatly increased by the addition of bismuth.

Cadmium.

36. Fig. 6 for cadmium shows that the load and impact strengths were slightly lowered by the addition of cadmium. Ulti-

Table 9

BRINELL HARDNESS ON BISMUTH IRONS

Test No.	Base Iron.	Addition, % bismuth.	Brinell Hardness No.				
			A	B	C	D	E*
1875	No. 2	1	286	444	444	444	460
1958	No. 1	1	166	166	187	269	277
1929	No. 2	0.25	351	430	430	430	444
1944	No. 1	0.25	179	183	179	207	207

* See Fig. 1 for locations on test bar.

Table 10

EFFECTS OF CADMIUM

Test No.	1918	1952	1926	1943
Base iron	No. 2	No. 1	No. 2	No. 1
Addition, % cadmium.....	1	1	0.25	0.25
Deviation of Treated Iron when compared with standards:				
(a) Chill, inches	+0.38	+0.02	+0.06	- 0.07
(b) Ultimate load, %.....	-9.8	-5.9	-1.6	- 4.2
(c) Impact strength, %.....	-7.1	-0.9	-4.8	-16.1
(d) Ultimate modulus, %.....	-3.8	-0.9	-2.8	+ 4.7
(e) Brinell No., avg., %.....	-1.8	-0.5	-1.3	- 6.7

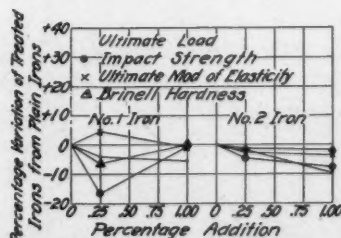


FIG. 6.—EFFECTS ON PROPERTIES OF TWO IRONS, WHEN VARIOUS PERCENTAGES OF CADMIUM ARE ADDED.

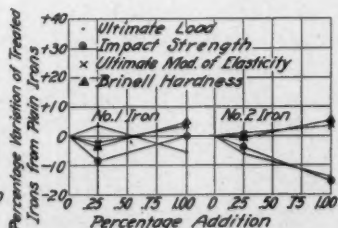


FIG. 7.—EFFECTS ON PROPERTIES OF TWO IRONS, WHEN VARIOUS PERCENTAGES OF METALLIC ARSENIC ARE ADDED.

Table 11

EFFECTS OF METALLIC ARSENIC

Test. No.	1886	1953	1964	1947
Base iron	No. 2	No. 1	No. 2	No. 1
Addition, % arsenic.....	1	1	0.25	0.25
Deviation of Treated Iron when compared with standards:				
(a) Chill, inches	+ 0.05	+0.01	-0.03	-0.03
(b) Ultimate load, %.....	-14.7	-5.9	-6.3	+3.8
(c) Impact strength, %.....	-15.1	0.0	-4.0	-8.5
(d) Ultimate modulus, %.....	+ 3.8	+3.4	+0.8	-1.9
(e) Brinell No., avg., %.....	+ 5.0	+4.3	-0.9	-3.3
Arsenic in test bars, %....	0.29	0.24	0.09	0.16

mate modulus and hardness also were somewhat affected. Chills were slightly deeper on No. 2 irons with cadmium.

37. Cadmium gave a series of explosions when the iron was added, and the amount of cadmium remaining in the metal was very doubtful. No determination of cadmium in the test bar was attempted.

Metallic Arsenic.

38. Fig. 7 gives the effect of additions of granular metallic arsenic to cast iron.

39. No. 1 iron showed above standard load with 0.25 per cent metallic arsenic addition, but increased addition lowered the load. No. 2 iron with 0.25 per cent arsenic had below standard load, which went lower with increased arsenic addition. The impact strengths all were below standard.

40. The ultimate modulus and hardness were approximately normal with the small addition but became above normal with one per cent arsenic additions.

41. The chill test showed very little effect for arsenic.

42. The amount of arsenic remaining in the iron was low and, as is shown by the chemical analysis, the arsenic content of the plain iron was 0.04 per cent.

Ferroarsenic.

43. In Fig. 8 the effect of adding ferroarsenic is shown graphically.

44. The load and impact strength on No. 2 iron remained

below standard but improved with higher arsenic content. This did not check with the result obtained by adding metallic arsenic. No. 1 irons containing either metallic arsenic or ferroarsenic have very similar loads.

45. The 0.25 per cent addition of arsenic to No. 2 iron gave abnormally high ultimate modulus and hardness as well as an all-white chill specimen.

46. The arsenic content of the test bar did not explain the effect obtained.

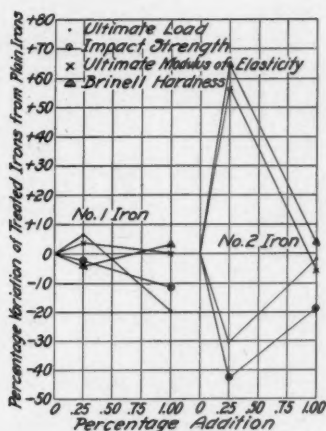


FIG. 8—EFFECTS ON PROPERTIES OF TWO IRONS, WHEN VARIOUS PERCENTAGES OF FERROARSENIC ARE ADDED.

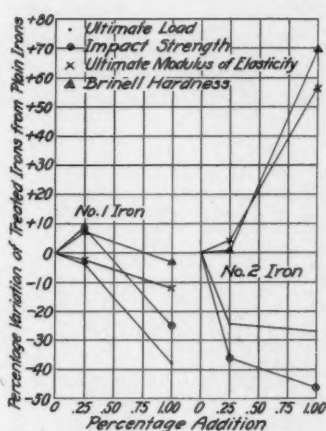


FIG. 9—EFFECTS ON PROPERTIES OF TWO IRONS, WHEN VARIOUS PERCENTAGES OF BRASS ARE ADDED.

Table 12

EFFECTS OF FERROARSENIC

Test No.	1887	1954	1930	1948
Base iron	No. 2	No. 1	No. 2	No. 1
Addition, % ferroarsenic.....	1	1	0.25	0.25
Deviation of Treated Iron when compared with standards:				
(a) Chill, inches	- 0.02	+ 0.02	+ 2.40	- 0.03
(b) Ultimate load, %.....	- 1.2	-19.5	-30.6	+6.7
(c) Impact strength, %.....	-18.1	-11.1	-42.3	-2.5
(d) Ultimate modulus, %.....	- 6.0	0.0	+56.9	+3.8
(e) Brinell No., avg., %.....	+ 3.2	+ 3.3	+64.1	-4.3
Arsenic in test bars, %....	0.14	0.17	0.11	0.08

Copper.

47. Fig. 10 shows the effect of copper additions. Load and impact strengths on No. 1 iron were above standard with copper additions, but decreased when the copper content was raised. The load on No. 2 iron was affected in a similar manner but to a less extent. The impact strength of No. 2 iron was below standard with copper.

48. The ultimate modulus on No. 2 iron was above standard with copper, and on No. 1 iron it was below standard; but it increased in both irons when copper content was raised. Chills showed very little change with copper additions.

49. Brinell hardness was raised on No. 2 iron and lowered on No. 1 iron by the addition of 0.25 per cent copper, but decreased when one per cent copper was added in both cases.

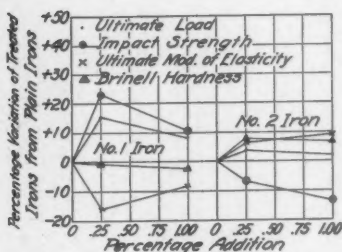


FIG. 10.—EFFECTS ON PROPERTIES OF TWO IRONS, WHEN VARIOUS PERCENTAGES OF COPPER ARE ADDED.

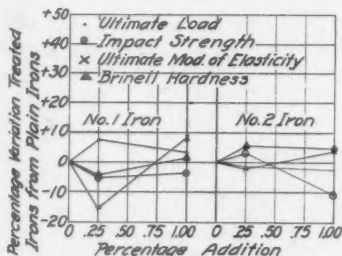


FIG. 11.—EFFECTS ON PROPERTIES OF TWO IRONS, WHEN VARIOUS PERCENTAGES OF TOBIN BRONZE ARE ADDED.

Table 13

EFFECTS OF COPPER

Test No.	1914	1966	1919	1937*
Base iron	No. 2	No. 1	No. 2	No. 1
Addition, % copper.....	1	1	0.25	0.25
Deviation of Treated Iron when compared with standards:				
(a) Chill, inches	— 0.03	+ 0.02	+0.13	— 0.02
(b) Ultimate load, %.....	+ 1.9	+ 8.0	+3.5	+15.3
(c) Impact strength, %.....	—13.7	+10.7	—7.0	+23.5
(d) Ultimate modulus, %.....	+ 9.0	— 8.5	+6.5	—16.0
(e) Brinell No., avg., %.....	+ 6.5	— 2.5	+7.5	— 0.4
Copper in test bars, %.....	0.76	0.84	0.36	0.34

* No. 1937 was compared with No. 1942.

Table 14
EFFECTS OF TOBIN BRONZE

Test No.....	1915	1882	1920	1938*
Base iron	No. 2	No. 1	No. 2	No. 1
Addition, % Tobin bronze.....	1	1	0.25	0.25
Deviation of Treated Iron when compared with standards:				
(a) Chill, inches	0.03	-0.01	-0.10	- 0.02
(b) Ultimate load, %.....	2.8	+3.8	-1.2	+ 7.2
(c) Impact strength, %.....	10.3	-3.4	+3.5	- 5.1
(d) Ultimate modulus, %.....	3.5	+8.3	-2.0	-16.0
(e) Brinell No., avg., %.....	+ 4.4	+1.4	+5.7	- 4.4
Copper in test bars, %....	0.58	0.53	0.21	0.26
Zinc in test bars, %.....	0.15	0.09	0.05	0.01

* No. 1938 was compared with standard No. 1942.

Table 15
EFFECTS OF BRASS

Test No.	1961	1862	1962	1965
Base iron	No. 2	No. 1	No. 2	No. 1
Addition, % brass.....	1	1	0.25	0.25
Deviation of Treated Iron when compared with standards:				
(a) Chill, inches	+ 2.12	+ 0.07	+ 0.64	+0.02
(b) Ultimate load, %.....	-27.1	-37.9	-24.5	-3.3
(c) Impact strength, %.....	-46.7	-25.0	-36.0	+8.6
(d) Ultimate modulus, %.....	+56.3	-12.2	+ 4.0	-2.5
(e) Brinell No., avg., %.....	+69.3	- 3.4	+ 0.4	+7.3
Copper in test bars, %....	0.78	0.86	0.24	0.24
Zinc in test bars, %.....	0.04	0.04	0.02	0.02

Tobin Bronze.

50. As shown in Fig. 11, there is one unreliable ultimate modulus obtained from a comparison with standard No. 1942.

51. Tobin bronze gave slightly less chilling than the plain iron. Tobin bronze composition was copper 70 per cent and zinc 30 per cent, really a brass.

Brass.

52. Fig. 9 shows the additions of brass to have been much more effective than were those of Tobin bronze.

53. The load and impact strength values for No. 2 iron with brass were much lower than those for No. 1 iron. Increasing the brass content, however, affected No. 1 iron more than No. 2 iron.

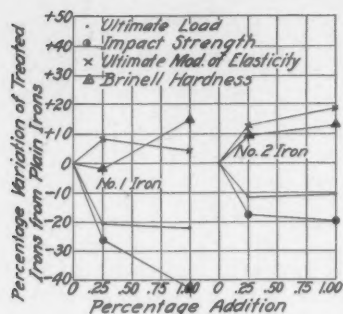


FIG. 12—EFFECTS ON PROPERTIES OF TWO IRONS, WHEN VARIOUS PERCENTAGES OF BEARING METAL ARE ADDED.

Table 16

EFFECTS OF BEARING METAL

Test No.	1893	1957	1927	1945
Base iron	No. 2	No. 1	No. 2	No. 1
Addition, % bearing metal.....	1	1	0.25	0.25
Deviation of Treated Iron when compared with standards:				
(a) Chill, inches	+ 0.23	+ 0.46	+ 0.19	+ 0.02
(b) Ultimate load, %	-10.8	-22.9	-11.8	-20.4
(c) Impact strength, %	-20.0	-42.4	-17.5	-26.2
(d) Ultimate modulus, %	+18.5	+ 4.2	+12.7	+ 8.5
(e) Brinell No., avg., %	+12.9	+14.9	+ 9.2	- 1.9

54. The ultimate modulus, Brinell hardness, and chill depth were remarkably high, without corresponding impact strength changes, in the case of a one per cent brass addition to No. 2 iron.

55. More zinc remained in the Ni-Resist (see Table 2) test bars than in the plain cast-iron test bars. This was possibly due to the presence of large amounts of nickel and copper in the "ni-resists," which metals tended to alloy with the zinc.

Bearing Metal.

56. Fig. 12 shows that white bearing metal definitely lowered the load and impact strength of both irons, having more effect on the softer No. 1 iron.

57. The ultimate modulus and Brinell hardness were increased in all cases except one. A deep chill was obtained with a one per cent addition of bearing metal to No. 1 iron.

IV—CONCLUSIONS

58. Lead, antimony, tin, bismuth, cadmium and bearing metal lowered the transverse and impact strength of both cast irons.

59. Arsenic (as metallic arsenic or ferroarsenic), copper, Tobin bronze and brass either raised or lowered the transverse and impact strengths, depending on the amount added, the nature of the base metal, and the amount of agitation and oxidation taking place in the ladle.

60. High ultimate modulus or stiffness usually was associated with lower impact strength, although this was not in any definite ratio. Lead was the outstanding exception, where ultimate modulus and impact strength gave practically parallel lines.

61. Widely different and even contradictory results on No. 1 and No. 2 irons were obtained in the effects of antimony on ultimate modulus and hardness; bismuth on ultimate modulus and hardness; metallic arsenic on transverse strength; ferroarsenic on transverse strength, ultimate modulus and hardness; copper on transverse and impact strengths, and ultimate modulus; brass on ultimate modulus and Brinell hardness; bearing metal on transverse and impact strengths, and ultimate modulus.

62. From the ordinary chemical analysis for silicon, sulphur, manganese, phosphorus and total carbon, there was no measure of these effects. An additional chemical analysis was helpful in the cases of antimony, tin and copper.

63. The depth of chill on the iron was greatly affected by some of the additions, especially in the cases where other results were far from normal.

64. Brinell hardness, especially when taken in various portions of the test bar, was an important aid in studying these irons.

65. The causes of abnormal physical properties in some gray cast irons might be traced to the presence of one or more of these metals.

Report on Definition of Gating Terms

Because of the numerous existing terms which are used in various foundries referring to identical types of gating, our committee was requested to make a survey of the industry and to recommend gating terms which, if approved, could be recommended by the Association for general use. Accordingly, your committee sent sketches of various types of gating to a list of representative foundries with the request that they indicate the terms that would be applied in their foundries. Approximately forty replies were received, which are summarized below.

The letters under each heading refer to the corresponding lettered sketches of Fig. 1, and the numbers refer to the numbered parts of each gating system. It will be noticed that certain terms are more favored than others, although for each part a large number of terms are used.

SUMMARY OF REPLIES TO QUESTIONNAIRE ON GATING NOMENCLATURE

A-1 Parting Gate—A			A-4			B-3		
Pouring cup	2		Gate	13		Gate	6	
Reservoir	1		Runner	10		Runner	15	
Pouring basin	11		Ingate	4		In gate	1	
Basin	5		Choke	1		Choke	1	
Cup	3		Reducing runner	1		Main runner	1	
Head	1		Main runner	1		Feeder	1	
Pot Gate	1		Feeder	1		Runner bar	1	
Sprue	3		Runner bar	1		Skim gate	1	
Pouring dish	1		Foot runner	1		Skim sprue	1	
Runner cup	1					Gate sprue	1	
Dish	1					Foot runner	1	
Sprue head	3		Parting Gate—B					
Bell	1		B-1					
Bowl	1		Pouring sprue	1		B-4		
Runner basin	1		Reservoir	1		Strainer sprue	2	
Runner neck	1		Pouring basin	11		Riser	6	
			Basin	5		Skimmer	5	
A-2			Cup	3		Open riser	1	
Sprue	18		Head	1		Strain gate	3	
Down gate	3		Pot gate	1		Sprue	1	
Down sprue	3		Riser	1		Skim riser	3	
Pouring sprue	1		Pouring dish	1		Dirt catcher	2	
Sprue neck	3		Runner cup	1		Relief sprue	1	
Upright	1		Dish	1		Pop off	1	
Stern	1		Sprue head	1		Skim gate	2	
Sprue choke	1		Bell	3		Stodge catcher	4	
			Sprue	2				
			Pouring cup	1				
			Runner basin	1		B-5		
A-3						Gate	15	
Dirt collector	1		B-2			Small end of choke	1	
Slag catcher	3		Sprue	19		Choke	5	
Dirt trap	1		Down gate	3		Casting feeder	1	
Slag trap	1		Pouring sprue	1		Shank	1	
Skimmer	8		Riser neck	1		In gate	2	
Skim gate	2		Upright	2		Gate mouth	1	
Skim bob	2		Sprue neck	2		Runner	1	
Top skimmer	1		Stem	1		Foot runner	1	
Stodge catcher	4		Runner neck	1		Gate neck	1	
Scum collector	1		Down sprue	2		Contact point	1	

NOTE: This report was presented before one of the sessions at the 1932 Convention of the American Foundrymen's Association.

Parting Gate—C

C-1	
Pouring cup.....	2
Reservoir.....	1
Pouring basin.....	11
Basin.....	5
Cup.....	3
Head.....	1
Pot gate.....	1
Sprue.....	1
Runner basin.....	1
Pouring dish.....	1
Runner cup.....	1
Dish.....	1
Sprue head.....	3
Bell.....	1

C-2	
Sprue.....	17
Down gate.....	3
Pouring sprue.....	1
Sprue neck.....	3
Upright.....	1
Stem.....	1
Runner neck.....	1
Down sprue.....	2

C-3	
Gate.....	5
Runner.....	12
In gate.....	2
Skim gate.....	1
Skim sprue.....	1

C-4	
Choke.....	17
Reducer.....	2
Skimmer.....	1
Neck gate.....	1
Choke gate.....	1
Reducing neck.....	1

C-5	
Gate.....	15
In gate.....	3
Runner.....	4

C-6	
Dirt collector.....	1
Slag catcher.....	2
Dirt trap.....	1
Slag trap.....	1
Skimmer.....	4
Double skim gate.....	1
Skim bob.....	2
Top skimmer.....	1
Skim basin.....	1
Stodge catcher.....	3
Scum collector.....	1
Skim gate.....	1

C-7	
Dirt collector.....	1
Dirt trap.....	1
Slag catcher.....	1
Trap.....	1
Skimmer.....	3
Double skim gate.....	1
Skim basin.....	1
Skim bobber.....	1
Bottom skimmer.....	1
Well.....	1
Scum collector.....	1
Stodge catcher.....	1
Skim gate.....	1

Parting Gate—D

D-1	
Pouring basin.....	16
Reservoir.....	1

D-1 (Continued)

Basin.....	7
Dish.....	1
Pot gate.....	1
Step gate.....	1
Runner box.....	1
Pouring dish.....	1
Side dish.....	1
Runner.....	1
Cup.....	1

D-2	
Neck.....	3
Dam.....	3
Overflow to sprue.....	1
Slag catcher.....	1
Trap.....	1
Dish skimmer.....	1
Overflow basin.....	1
Lip.....	1
Pouring basin neck.....	1
Skimmer.....	1
Overflow.....	1
Bridge.....	1
Choke.....	2
Basin skimmer.....	1
Breast.....	1
Skim gate.....	1

D-3	
Sprue.....	21
Down gate.....	4
Pouring sprue.....	3
Upright.....	1

D-4	
Gate.....	6
Runner.....	15
In gate.....	2
Main runner.....	1
Feeder.....	1
Runner bar.....	1
Sprue.....	1
Gate sprue.....	1
Foot runner.....	1

D-5	
Gate.....	15
Reducer.....	1
Choke.....	5
Castling feeder.....	1
Shank.....	1
In gate choke.....	1
Gate mouth.....	1
In gate.....	1
Foot runner.....	1
Gate reducer.....	2

Parting Gate—F

F-1	
Pouring basin.....	15
Basin.....	5
Sprue head.....	2
Pouring dish.....	2
Dish.....	2

F-2	
Sprue.....	16
Skim gate.....	1
Down sprue.....	3
Down gate.....	2
Runner.....	1
Upright.....	1

F-3	
Runner.....	7
Gate.....	1
Cope runner.....	1
Leader.....	2
In gate.....	1

F-3 (Continued)

Slag catcher.....	1
Upper skim gate.....	1
Skim gate.....	2
Skimmer.....	1
In gate (top).....	1
Skim basin.....	1
Sprue.....	1
Strainer gate.....	1

F-4

Strainer core.....	18
Skimmer core.....	6
Strainer.....	2

F-5

Strainer core basin.....	1
Gate.....	2
Drag runner.....	1
Runner.....	9
In gate.....	1
Leader.....	1
Choke.....	2
Lower skim gate.....	1
Catch basin.....	1
In gate (bottom).....	1
Bottom runner.....	1
Bottom skim basin.....	1
Under sprue.....	1
Strainer gate.....	1

F-6

Gate.....	16
Leader.....	2
In gate.....	4
Runner.....	1
Castling feeder.....	1

Parting Gate—G

G-1	
Pouring basin.....	15
Basin.....	8
Runner cup.....	3
Runner box.....	3
Dish.....	1
Runner blocks.....	1

G-2	
Ram-up core.....	1
Core.....	3
Drag sprue core.....	1
Drop core.....	1
Core for hot metal.....	1
To strike.....	1
Bottom core for down gate.....	2
Core on which iron is dropped.....	1
Splash core or plate.....	1
Bottom gate core.....	1
Ram-up gate cores.....	1
Impact core.....	1
Sprue plate core.....	1
Cutting preventer.....	1

G-3	
Pouring box.....	2
Runner box.....	11
Pouring cup.....	2
Built-up pouring well.....	1
Runner cup jacket.....	1
Basin ring.....	1
Box.....	1
Step gate.....	1
Jacket.....	1
Runner.....	1
Pouring basin.....	1
Head box.....	3
Runner gate.....	1

G-4		I-4 (Continued)		L-1 (Continued)	
Sprue	19	Leaders	1	Bell gate	1
Down sprue	4	In gate	3	Sprue	2
Down gate	4	Gates	12	Pouring dish	1
Runner	1	Casting feeder	1	Dish	1
Upright	1	Feeder shanks	1	Sprue head	3
		Sprues	1	Bell	1
		Set gates	1	Pouring cup	1
		Pencil gates	1		
G-5		Pencil Gate—J		L-2	
Gate	14	J-1		Strainer	6
Leader	1	Pouring basin	17	Strainer core	15
Runner	8	Basin	8	Strainer gate	1
In gate	5	Pop basin	1	Skim core	7
Casting feeder	1	Pouring dish	2	Sprue strainer core	1
Runner gate	1	Dish	2		
Foot gate	1	Pop gates	2	L-3	
Branch Gate—I		Runner cup	1	Sprue	12
Sprue	12			Down gate	3
Runner	2	J-2		Choke sprue	1
Pouring sprue	4	Finger gates	4	Pouring sprue	1
Pouring basin	4	Pencil gates	4	Sprue neck	3
Riser	2	Pop gates	7	Gate	3
Down gate	2	Sprue	2	Upright	1
Runner cup	1	Pencil	1	Stem	1
Feeder	1	Casting feeders	1	Neck	1
Cone feeder	1	Feeders	1	Down sprue	2
Cone sprue	1	Down gates	1		
Basin	1	Uprights	1	Wedge Gate—N	
Reamed for pouring	1	Spindle gate	1	N-1	
Sprue cup	1	Vertical pencil gates	1	Head	1
I-2		Runners	1	Basin	1
Riser	8	Pencil sprue	6	Knife gate basin	1
Skim sprue	1	Horn Gate—K		Wedge sprue	1
Vent	1	K-1		Pouring basin	3
Slag trap	1	Horn gate	14	Down sprue	1
Down sprue	1	Horn	2	Feeder	3
Strain sprue	1	Sprue	3	Wedge gate	1
Relief sprue and skim	1	Horn gate (large end)	2	Sprue	3
Strain gate	1	Runner	1	Wedge gate basin	1
Skimmer	1	Horn gate (top)	6	Pop gate	2
Skim riser	2	Horn sprue	6	Riser	5
Sprue	1	Gate	1	Top gate	2
Skimmer strain gate	1	K-2		Sink head	1
Dirt catcher	2	In gate	1	Cone riser	1
Relief sprue	1	Choke	4	Pop off	1
Skim gate	2	Gate	9	Wedge gate (top)	1
Pencil sprue	1	Casting feeder	1	Cone shaped sprue	1
Stodge catcher	2	Shank	1	N-2	
I-3		Horn gate	2	Neck	6
Runner	22	Horn gate (small end)	2	Gate	7
Pressure gate	1	Gate mouth	1	Knife gate	1
Leader	2	Neck	2	Choke	1
Main runner	1	Reducer	1	Casting feeder	1
Feeder	1	Top Gate—L		Wedge gate choke	1
Runner bars	1	L-1		Shank	1
Runner gate	1	Pouring cup	2	Neck of riser	3
Main sprue	1	Pouring basin	11	Flat gate	1
Trench supply	1	Basin	5	Riser end	1
I-4		Cup	1	Wedge gate neck	1
Finger gates	9	Head	1	Pop gate	1
Branch gates	2			Feeder mouth	1
				Wedge gate (bottom)	1

After studying the replies received, the committee has drawn up a series of recommended terms as shown in Fig. 1, having added certain types of gates which were not listed on the original questionnaire.

Terms as recommended were selected as being the most common in practice and also the most descriptive. For example, the

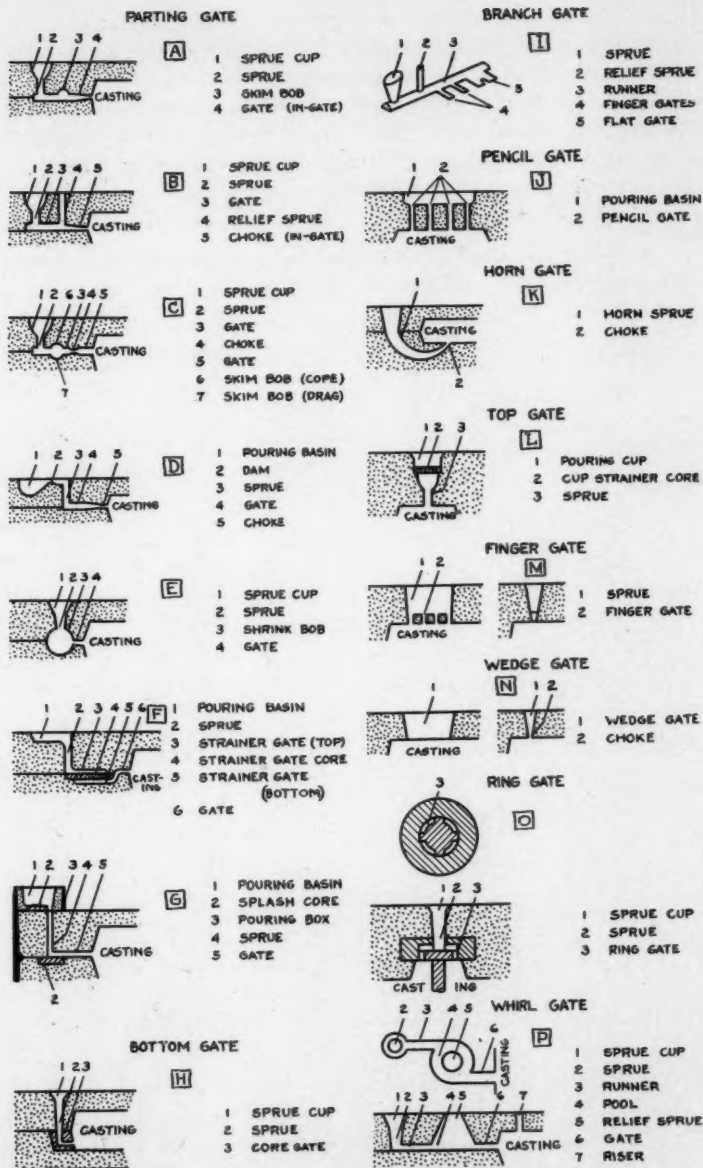


FIG. 1.

term "sprue" was selected as a proper term in preference, for example, to the term "down gate," inasmuch as the latter term would be so similar to the recommended term "in gate." Another example is the term "sprue cup," which was selected to designate the ordinary cupped sprue mouth in preference to such suggested terms as "pouring basin," "basin," and "pouring dish," in order to eliminate any possibility of using a term that would be similar to the recommended term "pouring basin."

The recommendations are submitted for criticism and discussion at the 1933 convention of the A. F. A.

Respectfully submitted,

H. W. DIETERT, *Chairman*

PAT DWYER

E. M. HANDLEY

*Sub-Committee on Gating Terms—
Committee on Nomenclature.*

Recommendations for Buyers of Castings*

Inquiries from buyers of castings should give the following essential information which is common to gray iron, malleable iron, steel and nonferrous castings:

(1) Kind of metal. If nonferrous, specify whether virgin, remelted, or secondary metal may be used.

(2) Sample of casting or detailed drawing.

(a) Sample castings, or

(b) Detailed drawing showing:

Actual or estimated weight of the casting.

Important dimensions, dimension tolerances and machined surfaces with amount of finish to be allowed.

Special requirements, such as finish, testing, gaging, special tolerances, disc or special grinding, etc.

Specific location, if any, for symbol number, pattern numbers and trade marks, and whether raised or sunken symbols are preferred.

(3) Number of pieces to be ordered of each pattern with delivery dates and schedules.

(4) Description of available pattern equipment and its condition, indicating:

(a) Type of Patterns:

Loose (number of patterns and if suitable for mounting on plate)

Gated (number on gate)

Plated (number on plate)

Machine, cope and drag (number on equipment)

* This report in tentative form was presented and approved before the Cost session at the 1931 Convention of the American Foundrymen's Association. Later it was submitted to the Iron and Steel Committee of the National Association of Purchasing Agents, which recommended certain minor changes. These revisions being approved by the A. F. A. Cost Committee, the recommendations were approved by the N. A. P. A. at their June, 1932, meeting.

- (b) Material from which pattern is constructed:
 - Wood (hard or soft)
 - Brass
 - Aluminum
 - White metal
- (c) Number of cores per casting with kind and type of core boxes:
 - Number of cores to each box.
 - Material from which core box is made.
 - Whether designed for core blowing machines.
 - Number and kind of core dryers.
- (5) If no pattern is available and foundry is to make pattern at customer's expense, customer should state whether substantially permanent patterns are to be constructed. If foundry is not to make pattern, it should have the opportunity to suggest how pattern should be made. If buyer is to furnish flasks, the size, type and construction should be given.
- (6) Description of the service or use of the casting. If the castings are to be subjected to pressure, give test to be made and method of making. Specify if test bars will be required in accordance with specifications published by the American Society of Testing Materials and by whom and where inspection or test will be made.
- (7) State whether pound, lump sum or piece price is desired, and F. O. B. point. Also if separate price is desired on pattern equipment.
- (8) Indicate any special crating, marking or packing.

Data for Specific Cast Metals

In addition to the foregoing information which inquiries for castings should show, and which is considered common to all kinds of castings, the following information has special application to specific kinds of castings.

GRAY IRON

- (1) Indicate special treatment, if any, such as sand-blasting, pickling, annealing, heat treating, normalizing, japanning, painting, enameling, polishing, etc.

MALLEABLE IRON

- (1) Are castings to receive any special finish, such as for galvanizing, sherardizing, plating, etc.
- (2) Are castings to receive special operations, such as straightening, drilling, drifting.

NONFERROUS

- (1) Physical and chemical specifications desired and tolerances permitted.
- (2) Are there any royalties to be paid by foundry.
- (3) Are castings to be heat treated, machined or to receive any special treatment, such as for plating, etc.

Recommendations for the Design of Nonferrous Castings*

ALL castings are designed with the thought in mind of answering a certain purpose or performing a given function and, in the selection of any particular alloy, these factors should always be uppermost in the designer's mind. In order, however, to attain the best ultimate results, factors which influence foundry practice and foundry technique must be given careful thought, bearing in mind that some very general considerations apply equally well to the casting of all nonferrous alloys whereas other considerations apply more specifically to a particular alloy or group of alloys.

The Committee on Recommended Practices, Nonferrous Division, of the American Foundrymen's Association, has compiled a list of suggestions relating to the design of nonferrous castings. These are given in the following paragraphs:

1. *Cooperation.* To avoid unnecessary expense, submit tentative designs to the foundry for suggestions as to possible changes, which, while not affecting the utility, may aid in simplifying the foundry practice and make a better or a cheaper casting, or both. Either the designer or the foundryman must visualize the molding methods applicable to the design and make such modifications as may be necessary to insure a good product.

2. *Draft.* Regardless of the type of pattern equipment, draft and shrinkage must be considered in all pattern designs. Sufficient taper on all vertical faces must be allowed to remove the pattern from the sand without excessive rapping and subsequent patching. (Fig. 1) Drawings should specify whether this draft is to be added to or subtracted from the casting dimensions as given, because such draft frequently affects the subsequent use of the casting.

* Approved for publication by Advisory Committee of A.F.A. Nonferrous Division. This material was prepared by a sub-committee of the Committee on Recommended Practices for Nonferrous Castings. The sub-committee was composed of the following: Chairman H. F. Seifert, Superintendent, Brass Foundry and Copper Dept., Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.; L. H. Fawcett, U. S. Naval Gun Factory, Washington, and T. D. Stay, Aluminum Co. of America, Cleveland.

NOTE: This report was presented and discussed before one of the sessions at the 1932 Convention of the American Foundrymen's Association.

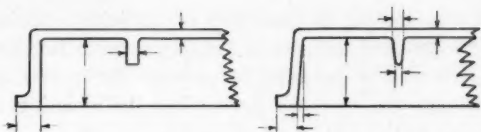


FIG. 1—CASTING WITHOUT (Left) AND CASTING WITH (Right) PROPER TAPER FOR EASY REMOVAL OF PATTERN FROM THE SAND.



FIG. 2—IRREGULAR (Left) VERSUS REGULAR (Right) PARTING LINES.

3. *Shrinkage, Patternmaker's.* Shrinkage is an important consideration in the production of castings and must be considered and allowed for, not only by the patternmaker and foundryman but also by the design engineer. On average size brass castings, $3/16$ inch per foot is the customary allowance. The usual shrinkage allowance on average size aluminum-alloy castings is $5/32$ inch per foot. The total amount of shrinkage in any casting depends largely upon its size and shape, and its freedom to contract in the mold during cooling.

4. *Parting Lines.* Parting lines should be made as even as possible to facilitate molding. Avoid irregular and multiple parting lines because they tend to molding complexities, dimensional irregularities and increased cleaning costs. (Fig. 2)

5. *Locating Points.* Locating points to be used by the machine shop should be indicated on the drawing so that castings may be satisfactorily checked, always from the same point of origin, by the pattern shop, foundry or machine shop. They should be so placed as not to be influenced by a core shift. The points should be as far apart as the size of the casting permits, in order to insure the most accurate results. The jig spots are very important items frequently neglected until the casting is made, with much subsequent loss.

6. *Dry-Sand Cores.* It is desirable, wherever possible, to avoid dry sand cores, primarily because of the higher cost. (Fig. 3) Where the cooling metal contracts around a dry-sand core, strains and cracks frequently develop because the core does not yield sufficiently to the cooling metal as it contracts. This is of particular importance on aluminum alloys and on many of the

brasses. Cores should be designed of sufficient thickness to be satisfactorily handled and set without excessive breakage. Sufficient thickness also is desirable to prevent the molten metal from burning through the core and increasing the cleaning cost.

7. *Green-Sand Cores.* Green-sand cores are preferable to dry sand wherever it is possible to use them, because of lower cost, cheaper cleaning expense, etc. (Fig. 2)

8. *Finishing.* The design of a casting often is a serious consideration in the cleaning and trimming cost, which may far outweigh the molding cost. It is well for the designer to keep in mind the expense involved in cutting off risers in inaccessible spots on the high-shrinkage alloys such as manganese-bronze or iron-aluminum bronze, or on the alloys difficult to machine, such as gear bronze.

9. *Section Uniformity.* Uniformity of section thickness is very desirable from a foundry standpoint. (Figs. 4, 5 and 6) This equalizes the rate of solidification, which is a very essential consideration for the manufacture of quality castings, and simplifies both the gating and the feeding. Non-uniform solidification

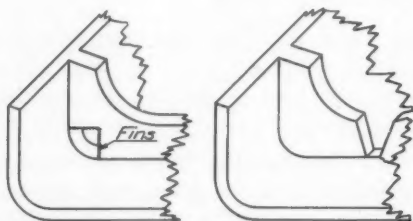


FIG. 3—EXAMPLES OF CASTING MADE WITH (Left) AND WITHOUT (Right) A CORE. IN RIGHT FIGURE, NOT ONLY IS CORE ELIMINATED, BUT CLEANING LABOR AND PATTERN COST ARE CONSIDERABLY REDUCED.

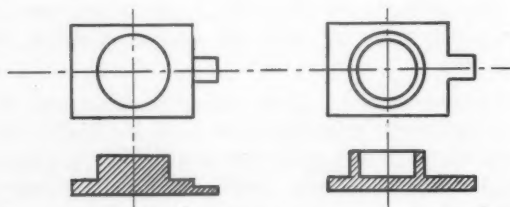


FIG. 4—UNDESIRABLE (Left) AND DESIRABLE (Right) DESIGN OF LUG OR BOSS FROM STANDPOINT OF METAL SECTION.

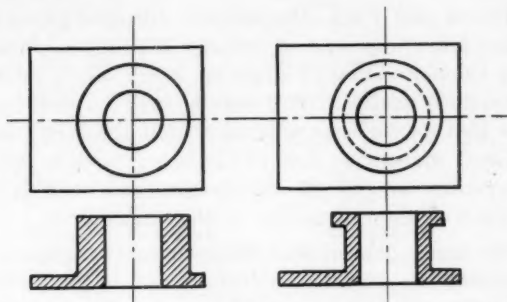


FIG. 5—FLANGE BODY OF VARYING (Left) AND UNIFORM (Right) METAL SECTIONS, BOTH OFFERING THE SAME BOLTING SURFACE.

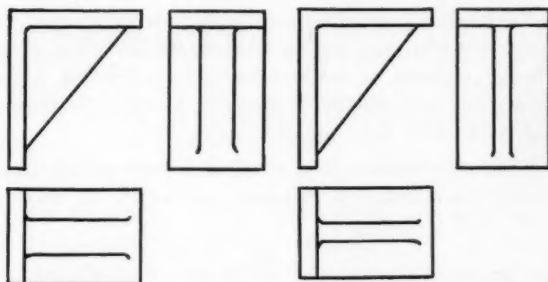


FIG. 6—RIB POORLY DESIGNED (Left), AND RIB OF PROPER PROPORTIONS (Right) WITH PROPER TAPER FOR EASY REMOVAL OF PATTERN FROM SAND.

sets up internal strains and causes shrinkage defects and cracks.

10. *Joining Sections.* Where the design is such that light and heavy sections join, a gradual increase is desirable in the thickness of the thinner section toward the point of junction. (Fig. 7)

11. *Minimum Section Thickness.* The nonferrous foundryman frequently is asked what minimum section thickness he can successfully cast. This, of course, varies materially with the alloy, the size and intricacy of the casting, the pressure requirements, etc. Castings poured at an excessive temperature to run very thin sections generally are deficient in physical characteristics and should be avoided. On brass and bronze, $3/32$ inch is considered the minimum satisfactory metal section. With aluminum alloys, $1/8$ inch has been cast satisfactorily, although a minimum thickness of $3/16$ inch is preferable.

12. *Bosses and Lugs.* Bosses and lugs are common in all castings and frequently lead to foundry difficulties. Where they join onto a thinner section of a casting, non-uniform solidification must be provided against. This may be accomplished by a riser acting as a feed for the boss, or a metal chill (generally cast iron) may be placed against the face of the boss. Such a chill simply tends to equalize the rate of solidification and make it more or less identical with the thin section of the casting.

13. On larger nonferrous castings, bosses frequently are designed specially to maintain uniformity of metal sections and thereby simplify the foundry practice and at the same time make a stronger job. The saving in material cost is an added consideration.

14. Bosses and lugs often are located on an interior portion of a casting, in which case the casting should be so designed as to provide heavy sections of metal leading to a feeding source; or some special provision should be made to provide for these heavy sections, as with chills, for example. (Fig. 8)

15. *Fillets.* Generous fillets at all intersections will materially reduce foundry scrap due to shrinkage and cracks at these points.

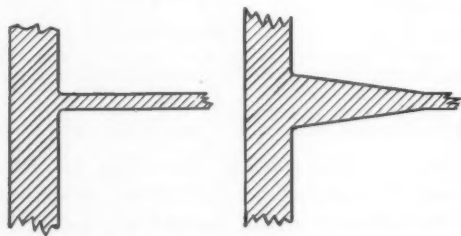


FIG. 7—UNDESIRABLE (Left) AND DESIRABLE (Right) JUNCTION OF LIGHT AND HEAVY SECTIONS.

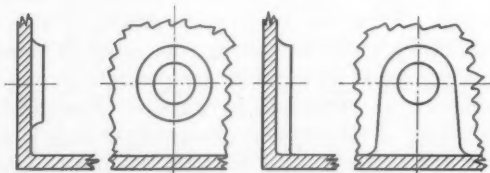


FIG. 8—LUG OR BOSS AT Left REQUIRES LOOSE PIECE, WHEREAS LUG AT Right EXTENDS TO BOTTOM FLANGE, ELIMINATING NEED FOR LOOSE PIECE OF PATTERN AND SIMPLIFYING THE MOLDING.

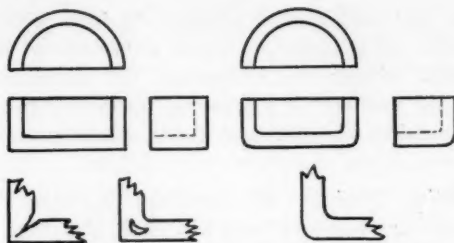


FIG. 9—DESIGN AT *Left* HAS TENDENCY TO SHRINKAGE CRACKS AND SHRINKAGE CAVITIES BECAUSE OF SHARP ANGLES AND ABSENCE OF FILLETS. PROPER DESIGN AT *Right* WITH AMPLE FILLETS.



FIG. 10—POOR (*Left*) AND GOOD (*Right*) CROSS-SECTIONAL DESIGN. PIPING IS PREVENTED AND STRENGTH IS INCREASED BY METAL DISTRIBUTION SHOWN IN DESIGN AT *Right*.

Sharp angles are apt to produce sand wash in a mold and are a source of weakness in the casting. (Fig. 9)

16. *Ribs*. Ribs are used primarily as stiffeners and reinforcing members in general. The rib sections should have a fair relation to the casting section, inasmuch as the pouring temperature is governed to a considerable degree by the thinnest section in the casting. Thin ribs, also, because of rapid cooling, may set up casting strains and cracks. (Fig. 10)

17. *Pockets*. Deep pockets and small recesses that complicate drawing the pattern from the sand or lifting the cope should be avoided.

18. *Metal Inserts*. Inserts, generally iron or steel, occasionally are cast into aluminum castings such as handwheels and, into gear-bronze blanks, overhead trolley-line suspension castings, etc. Such inserts should be knurled or grooved to insure mechanical bond, and sufficient metal must be provided around such inserts to eliminate cracks during solidification.

19. *Machine Finish Allowance*. Machine finish allowance must be specified whenever castings are to be machined, due consideration being given to size of casting, alloy, and machine set-up.

On small-size and medium-size castings $\frac{1}{8}$ inch is a customary allowance, with correspondingly larger allowance on larger castings. On split railway motor bearings the allowance is about $\frac{1}{64}$ inch at the parting for a grinding operation, and $\frac{3}{32}$ inch each on the outside diameter and inside diameter on a side for machining.

20. *Molding Position of Machined Surfaces.* Machined surfaces, wherever possible, should be cast in the drag, since then there is less chance of these surfaces containing defects such as shrinkage, dross and blowholes, than with those surfaces in the cope. Where such finished surfaces must be cast in the cope, an extra finish allowance should be made.

21. *Welding and Soldering.* The welding and soldering of minor defects on nonferrous alloy castings is a recognized operation. It should be used with discretion, however, and only by experienced welders.

CONSIDERATION OF ALLOYS

22. In the selection of an alloy for any particular application, the design engineer is influenced primarily by the physical characteristics such as strength, hardness, density, resistance to wear, weight, anti-frictional properties, conductivity, corrosion resistance, shrinkage, melting point, color, polishing qualities, etc.

23. Often the demand is for a combination of a number of qualities in one and the same casting, and the designer may then find it necessary to compromise between the various characteristics that he desires to incorporate in any one casting.

24. Aside from the physical characteristics desired, the design engineer is governed in his choice of alloy by the foundry technique available in the particular foundry doing the work, by the facilities of that particular foundry, and by the cost of the metal. All these factors markedly influence design and must receive careful consideration from the design engineer.

25. The material cost in nonferrous castings is a factor of great importance and makes up a high percentage of the total cost. For that reason the engineer must keep it constantly in mind and keep the design of his casting down to the minimum weight consistent with good engineering practice.

26. In general, under normal conditions, the high-zinc low-

copper brasses or the yellow brasses have the lowest intrinsic metal value. The low-zinc high-copper or red brasses follow in order. Then come the copper-tin bronzes and special mixtures. The aluminum alloys must be considered separately.

27. The high-zinc low-copper or yellow brasses, while the cheapest from a material cost standpoint, are objectionable in the foundry because of zinc fume, dross and resultant dirty castings. They also have relatively high shrinkage or liquid contraction, resulting in poor casting characteristics.

28. The aluminum alloys, while expensive per unit of weight, go approximately three times as far per unit of volume as do the brasses and the bronzes. This is a very important factor for the design engineer to consider.

29. Unusual shrinkage in an alloy requires excessive risers and suitable feeds. In all such cases the weight of a casting ultimately shipped is only a small percentage of the weight of metal melted to pour such casting. The cost is correspondingly high, and this ratio between weight of metal melted and weight of metal shipped should be recognized.

30. Alloys requiring special manipulation, special equipment or a high foundry technique, should not be undertaken unless the foundryman is thoroughly familiar with the problems involved and is prepared to meet them.

PATTERN EQUIPMENT

31. Pattern equipment for use in the production of non-ferrous alloy castings is not unlike that for iron foundry or steel foundry use. The design and intricacy of casting, the activity and the production methods of the particular foundry doing the work, determine the type of equipment best suited for the production of any particular casting.

32. In general, patterns for nonferrous work may be classified as follows:

- (a) Single loose wood or metal patterns.
- (b) Gated wood or metal patterns.
- (c) Metal match plate patterns.
- (d) Wood cope and drag patterns.
- (e) Metal cope and drag patterns.
- (f) Special pattern equipment.

33. Single loose wood patterns are relatively cheap but should be used only for a very limited production. Such patterns are easily warped by moisture and damaged in handling. They fit in well where an experimental piece of apparatus is being built which is subject to more or less development, and where only one or two castings are required off a pattern.

34. Loose metal patterns are recommended in all cases where the production is small and where there is only a limited amount of money available for pattern equipment.

35. In both loose wood and loose metal patterns the time required by the molder to cut gates and risers by hand often is equal to the time required for the making of the mold itself. This materially affects the cost of producing castings with this type of equipment.

36. Gated wood patterns may be used for small quantity production of simple castings, but this type of equipment is open to the same general criticism as single loose wood patterns in regard to warpage and breakage.

37. Gated metal patterns are very satisfactory for small quantity production. The location of gates and risers on such patterns should be left to the judgment of the foundry.

38. Metal match-plate patterns for large quantities of small castings assure rapid and accurate reproduction. This type of equipment involves a greater initial expenditure, which is amply compensated for by other savings when the cost of the patterns is spread over a large quantity production.

39. Separate cope and drag patterns, whether of wood or metal, permit of good production on medium to large castings because one molder or group of molders may ram up the drag while another molde. or group may work on the cope if the production requirements demand.

40. Metal cope and drag pattern equipment is particularly applicable for large production of heavy castings and to gang molding on machines.

41. Special pattern equipment, sweep patterns, skeleton patterns, etc., find only very special application in nonferrous casting work. The design engineer would do well to consider them only after consultation with the pattern maker and the foundryman.

Practical Foundry Considerations for Improving the Soundness of Aluminum-Alloy Castings*

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Abstract

The authors pay special attention to causes of unsoundness and methods for overcoming defects of this type. Pinholes are said to be due almost exclusively to (1) metal shrinkage during solidification, (2) occluded gases, or (3) combination of these two factors. In suitably designed castings it is definitely established that soundness generally can be obtained by proper foundry technique. The foundry factors are grouped as (1) metal melting and pouring temperatures, (2) melting furnaces and fuels, (3) foundry technique, (4) alloys and alloy constituents, and (5) condition of metal as determined by previous history. Each of these factors are discussed in detail. Data from experimental work on determining effects of foundry factors on soundness are presented, together with methods of suppressing pinhole porosity.

Introduction

1. It is generally recognized that in making sand castings from any of the commercial metals, certain factors must be considered in order to obtain sound castings. These factors start with the drafting board and end with the pouring of the metal into the mold; they involve not only design but also metal handling and foundry technique.

2. Foremost among the requirements for every casting is the necessity for sufficient strength to meet the demands of service. It is a well-established axiom that the strength of a casting depends to a large degree upon its soundness, and that the soundness in a casting depends upon variables which can be controlled. It is the purpose of this paper to point out not only how these variables affect the soundness of aluminum alloy castings but also

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how suitable design, careful metal handling and proper foundry technique improve the quality of the casting.

3. Much has been written in the past on the subject of unsoundness in all types of castings, and considerable stress has been laid on pinhole porosity. This type of porosity, which may at times occur and prove troublesome, consists of small cavities or pores distributed throughout certain areas of the casting, but which are seldom detected on the "as cast" surface. The size and shape of the cavities or pores may vary from less than 0.30 mm. to as much as 3.00 mm. in diameter. They may be spherical in shape or they may appear elongated and irregular and resemble intercrystalline cracks.

Other Types of Unsoundness

4. While other forms of unsoundness, such as blowholes, sand holes, cracks and shrinkage cavities, may have more harmful effects on the strength of the casting, they can be more easily detected and eliminated. Blowholes, while usually spherical in shape, generally are larger and result from trapped core gas or air which cannot escape before the metal solidifies. Sand holes are the result of particles of sand introduced in the mold which leave their impression on the final casting. Cracks and crystallization or eutectic shrinkage may be the result of a number of factors and usually can be distinguished from the other types of defects.

5. Recommended practices for making sound aluminum-alloy castings have dealt almost entirely with the preparation and handling of the metal, losing sight of the effect of foundry technique. The investigations covered in this paper include (a) the factors which may cause pinhole porosity; and (b) suitable methods of preventing their occurrence.

CAUSES OF PINHOLE POROSITY^{1*}

6. A casual observation of the varied occurrences of pinhole porosity may lead one to conclude that there are as many causes as effects. More careful analysis, however, has shown that this is not true. It is now well established that pinholes are due to (1) metal shrinkage during solidification; (2) occluded gases either in the metal or its oxide, liberated as the metal cools, or (3) a combined effect of both shrinkage and occluded gases.

* Reference numbers shown herein correspond with numbers given in Bibliography at end of paper.

7. The greater part of the pinhole porosity occurring in aluminum alloy castings no doubt is due to the latter combination. Actual cases of porosity due solely to either shrinkage or gas evolutions are quite rare.

8. The effect of shrinkage upon pinhole porosity in aluminum castings has never been studied very extensively. Although a number of theories have been advanced^{2, 3} from time to time, experimental evidence to support them is still lacking. The study of gases in aluminum and their removal has been the object of somewhat more thorough investigation.^{4, 5}

9. In the following discussion, it is not the authors' idea to advance any new theories in this connection. However, in the discussion we want to point out the various experimental results which we have found to have some bearing on this question.

General Cause of Voids and Shrinks

10. Aluminum and its alloys, like other metals, contract or shrink upon solidification. This is evidenced by several prominent facts, namely, the change in volume between the pattern and casting, marked pipes in the tops of sprues and risers, and external and internal shrinks. Microscopic and chemical analyses of the metal adjacent to shrinkage areas, especially when internal, have revealed the presence of a low melting metal of eutectic composition, indicating that this particular area was one of the last to solidify. The inevitable result of the unequal rate of cooling and solidification of internal molten areas is a void or shrink.

11. A certain relation between these large shrinkage areas and pinhole porosity has been found to exist. Microscopic studies of numerous aluminum-alloy castings have shown a certain amount of eutectic alloy and dross or aluminum oxide in the immediate vicinity of pinholes. This would seem to indicate that the metal in the area in which the pinholes predominate was the last to solidify, and as such would be subject to shrinkage of some nature.

12. When this condition is widely distributed throughout the metal the shrinkage may readily take the form of pinhole porosity, in the majority of cases existing as inter-granular shrinkage. As the conditions governing this shrinkage become worse, the porosity becomes larger and in some cases actually forms a complete network of intercrystalline shrinkage or channel porosity, so named because of fine connecting channels between pores (Figs. 1, 2).

13. As mentioned before, considerable investigation has been carried out in connection with the absorption of gases by aluminum alloys and their effect on the condition of the metal upon solidification. Hydrogen has been reported as having by far the greatest solubility in aluminum. During solidification of an alloy from the molten condition, a certain amount of the gas which may be held in the metal in some form escapes before the pasty state is reached.⁶ The occluded gas which escapes or is freed from solution at the precise moment of solidification causes a void. Such porosity, resulting entirely from occluded gases, appears as well-rounded

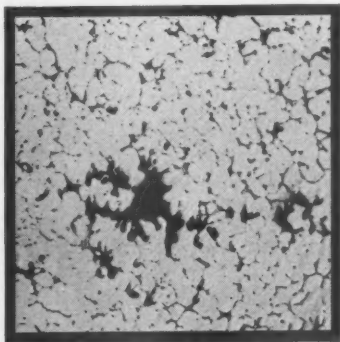


FIG. 1—PHOTOMICROGRAPH SHOWING PINHOLE POROSITY IN ALUMINUM-ALLOY CASTING DUE PRINCIPALLY TO INTERCRYSTALLINE SHRINKAGE. NOTE IRREGULAR CONTOUR OF CAVITIES. X25.

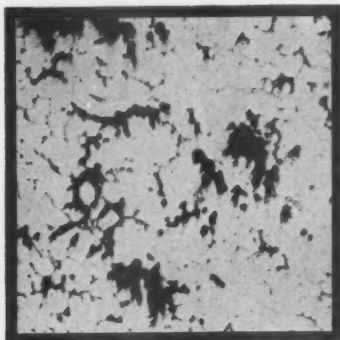


FIG. 2—PHOTOMICROGRAPH SHOWING EXTREME CASE OF PINHOLE POROSITY IN ALUMINUM-ALLOY CASTING DUE PRINCIPALLY TO INTERCRYSTALLINE SHRINKAGE. THIS TYPE OF POROSITY, BECAUSE OF CONNECTING CHANNELS BETWEEN CAVITIES, IS GENERALLY CALLED CHANNEL POROSITY. X25.

cavities with very smooth walls. Many of these are easily distinguished by the rather silvery interior of each cavity (Fig. 3).

14. A quite logical connection between the effects of internal shrinkage and occluded gases can easily be seen. Since both the release of a substantial amount of gas from the metal and the maximum shrinkage occur at approximately the same metal state, it is not unlikely that the gas may segregate in the shrinkage cavities. These shrinkage areas, being the last to solidify, afford a place for the trapped gas that is trying to escape from the metal. Porosity caused by this combination effect assumes more the irregular shrinkage appearance than a definitely rounded form.

FACTORS INFLUENCING THE SOUNDNESS OF ALUMINUM ALLOY CASTINGS

15. It is not to be concluded from the previous discussion that unsoundness in the form of pinhole porosity exists in all aluminum-alloy castings. In suitably designed castings, it is definitely established that soundness of the metal generally can be obtained by proper foundry technique. It is admitted that some castings lend themselves more readily to this control than do others which necessitate individual consideration by the foundry. Those foundries familiar with the factors involved and equipped with the necessary means of control should have little difficulty in producing sound aluminum-alloy castings.

16. Assuming that the unsoundness under consideration is due to the combined effect of solidification shrinkage and occluded

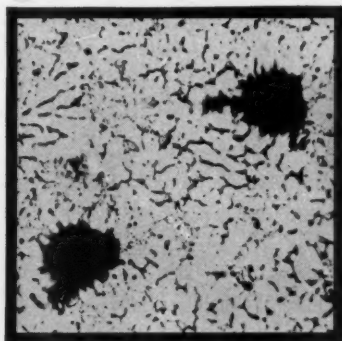


FIG. 3—PHOTOMICROGRAPH SHOWING PINHOLE POROSITY DUE PRINCIPALLY TO ENTRAPPED GAS. NOTE ROUNDED CONTOUR OF CAVITIES. X25.

gas, there are a number of factors, variables in the metal-handling process and foundry technique, which may influence the magnitude of their effect. Among these can be listed the following:

- (a) Metal melting and pouring temperature.
- (b) Melting furnaces and fuels.
- (c) Foundry technique.
- (d) Alloys, alloying constituents.
- (e) Condition of metal as determined by previous history.

17. Considerable published data as to the results of the above factors on aluminum alloy castings are available, and probably

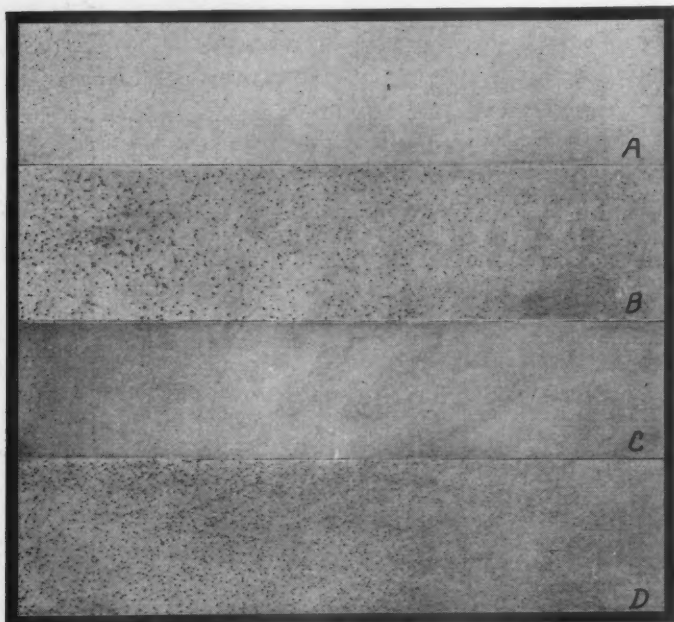


FIG. 4—SAND-CAST ALUMINUM-ALLOY STEP SLABS MADE WITH DIFFERENT FOUNDRY CONDITIONS AND MACHINED TO SHOW EXTENT OF PINHOLE POROSITY. SECTIONS ARE GRADUATED FROM LEFT IN FOUR STEPS FROM 25 MM. TO 6.3 MM. IN THICKNESS. A: SLAB CAST AT 1300 DEGS. FAHR. FROM METAL MELTED AT 1450 DEGS. FAHR. B: SLAB CAST AT 1450 DEGS. FAHR. FROM METAL MELTED AT 1500 DEGS. FAHR. C: SLAB CAST AT 1400 DEGS. FAHR. FROM METAL MELTED AT 1500 DEGS. FAHR.; SAND MOLD CHILLED IN DRAG WITH METAL CHILLS. D: SLAB CAST AT 1250 DEGS. FAHR. FROM METAL MELTED AT 1340 DEGS. FAHR.; SAND MOISTURE 10 PER CENT AS OPPOSED TO REGULAR 6 TO 7 PER CENT MOISTURE.

familiar to most foundrymen.⁷ However, since the effect of these factors and the necessity for their control cannot be overemphasized, they are briefly reviewed below.

Metal Melting and Pouring Temperature.

18. It is now a well-established fact that the ability of aluminum alloys to absorb gases, either by solution or reaction, increases rapidly with the temperature and the time such metal is held at these elevated temperatures. This fact leads to the conclusion that, for minimum gas absorption, the temperature of any of the melting operations should be as low as possible and the holding time as short as possible.⁸ Accurate temperature control during melting and pouring in itself eliminates a large amount of the pinhole porosity sometimes found in aluminum-alloy castings.

19. Low metal temperatures, particularly low pouring temperatures, also play an important part in the control of shrinkage. A high pouring temperature, in addition to producing an undesirable grain structure,⁹ often produces large temperature gradients between the metal in various locations. This condition prevents the ideal uniform and rapid progressive cooling desired for minimum internal shrinkage.

20. To illustrate the effect of temperature on the soundness of castings, polished sections of similar castings poured at different temperatures are shown in Figs. 4-A and 4-B. It will be noted that in every case the lower the melting and pouring temperature, the sounder the resulting casting. In the case of castings made from metal melted at excessively high temperatures, the pinholes are somewhat more rounded, indicating the presence not only of more gas but of greater intercrystalline shrinkage at these elevated temperatures than at lower temperatures.

Melting Furnaces and Fuels.

21. The question of types of furnaces and fuels best adapted for the melting of aluminum alloys is still a subject of some controversy. Obviously, the economics of the melting operation enter into this question. From this standpoint, time of melting, fuel costs and furnace maintenance are perhaps the most important, although often it is through too rigid melting economy that the soundness of the final casting is forgotten. However, it is not the purpose of this paper to discuss furnace and fuel economy but

rather to comment on the effect of these factors on the soundness of castings.

22. There is probably little question as to the possibilities of contaminating aluminum alloys through improper furnace and fuel control.¹⁰ In gas- or oil-fired furnaces of either the stationary or tilt type, employing iron, graphite or vitreous pots and an indirect external flame, the chances of gas being taken up by the metal are relatively small unless excessive overheating occurs. In reverberatory furnaces with direct-flame heating, the metal is more susceptible to gas absorption and hence additional precautions must be taken. Temperature control must be quite rigid, and the temperature maintained as low as possible.¹¹

23. Melting equipment should be properly maintained and cleaned at all times. The necessity for proper care of this equipment cannot be stressed too greatly, since the effect of contamination of the metal from dirty equipment often reflects on the soundness of the castings produced.

Foundry Technique.

24. Every foundryman no doubt will agree that foundry technique is an important factor in the production of sound castings in any alloy. The ability to apply the proper technique to insure sound castings is a foundry art developed principally through experience. There are, of course, certain fundamental laws which must be followed for best results. Because of the great variety of individual problems in technique which arise in the foundry, and the necessity of separately considering each particular casting, the following discussion must be made relatively general.

25. *Rate of Solidification.* That the rate of solidification of an aluminum-alloy casting has considerable effect on the soundness, can be seen by examining permanent-mold castings. In this case, the iron molds accelerate the cooling to such an extent that any gas is retained in solid solution or otherwise held in the metal. Permanent-mold castings, therefore, are relatively free from pin-hole porosity and are more sound than similar castings made by other methods.

26. The ideal cooling condition for promoting maximum soundness in castings is a uniform, rapid, progressive solidification proceeding from points furthest from the gates toward the gated

areas. Such progressive cooling should be worked out for each particular type of casting so that the metal, as it solidifies and contracts, is fed by molten metal immediately adjacent. At the same time, any occluded gas or oxide will be better able to escape into the risers provided to maintain a reservoir of molten metal for feeding the last section of the casting to solidify. Risers, to be of maximum benefit, must remain molten until the last.

27. It is often necessary in the case of sand castings to chill the heavy sections by means of metal chills, in order to obtain a uniform, progressive solidification (Fig. 4-C). Metal chills of any nature, however, must be used with discretion or they will defeat their own purpose. The over-chilling of castings, although possibly increasing the soundness in the immediate chilled area, may destroy the ideal progressive solidification and cause unsoundness in other areas. There is no hard and fast rule regarding chilling; the amount of chill and areas to be chilled are more or less matters of experience and trial.

28. *Section Thickness.* The effect of section thickness also is intimately associated with the rate of solidification. It is natural that the section thickness should have an influence on the soundness of castings. The greater the section thickness, the slower will be the cooling and the more pronounced will be any unsoundness due to occluded gas and shrinkage. For this reason more foundry care is necessary with castings of heavy section.

29. The effect of section thickness and rate of solidification is well illustrated in Figs. 4-B and 4-D. The casting sections shown vary in thickness from 25 mm. at one end to 6.3 mm. at the other. The maximum porosity occurs in each case in the heavier sections. By proper chilling of these heavier sections to insure the ideal solidification, a marked increase in soundness is shown.

30. *Feeding.* A discussion of the effect of the various methods of gating and feeding on the soundness of a casting is necessarily difficult owing to the number of factors involved. The ideal feeding, like the ideal rate of solidification, should aim toward progressive solidification to the points of metal delivery—either sprues or risers. In every case these should be so placed as to be the last points to solidify. In this way they will more efficiently perform their function of providing an exit for occluded gases and oxides, as well as a source of liquid metal to feed the casting as it solidifies.

31. Due to casting design, mold construction, trimming con-

siderations and other factors inherent in sand castings, ideal feeding conditions are not always easily obtained. To simplify this problem requires close cooperation between the designer and foundryman. The designer should not hesitate to consult the foundry and obtain their comments on the adaptability of every new design to meet foundry requirements, even before the pattern is made. Such cooperation in itself will do much toward the production of sounder castings.

32. The distribution of metal in the mold also constitutes a part of this problem. A casting should be gated with the idea of delivering the colder metal to the heavier sections. For this reason, gates should be cut into the thin sections of the casting when possible, rather than into the heavier sections. Multiple gates usually are to be desired since they not only permit more rapid filling of the mold cavity but also reduce the temperature gradient of the metal in the mold, promoting more rapid solidification.

33. Risers of ample size should be located to feed the heavier sections of the casting. As previously mentioned, they should remain liquid for some time after the casting has solidified to give the desired results. Risers, however, should be used only where they are necessary; when incorrectly placed they often cause external shrinkage or cracks, which are no more desired than pinhole porosity.

34. *Molding and Core Sands.* Although not generally recognized, the physical properties of the molding and core sands may materially affect the soundness of aluminum-alloy castings. In order to provide the least resistance possible for the escape of both the occluded gases that may be present in the metal and gases that are generated in the mold, the sand should be as open as possible.

35. Sand moisture is another variable which warrants careful manipulation, since the reaction of the molten metal with the moisture in the sand is such as to result in considerable gas evolution (Fig. 4-D). No more moisture should be added to the sand than necessary for efficient working. Some types of core binders produce more gas than others when the cores come in contact with hot metal. Such core binders should be avoided as much as possible.

36. The determination of the best sand permeability, moisture and binder content, and the regular routine control of these factors, are necessary for maximum soundness in castings.

37. *Pouring.* The final factor warranting consideration is

that of pouring technique. Although other forms of unsoundness in castings as a result of pouring practice may generally be more pronounced than pinhole porosity, there is evidence to show that pinhole porosity sometimes can be attributed to this factor.¹² To reduce as much as possible metal turbulence during pouring, the pouring height should be held to a minimum. The stream of metal should not be broken at any time during the pouring operation. By adhering to these rules, a minimum exposure of the molten metal to steam and air will result, with less possibility of trapped and absorbed gas.

Alloys and Alloying Constituents.

38. It is well known that certain aluminum alloys have better casting characteristics than others. This condition sometimes may be traced to the metallic elements entering into the alloy, impurities such as oxides and nitrides which may be present, or to the nature of the alloy itself. The control of the first two factors is best accomplished in the alloying practice through a knowledge of the characteristics of the various elements. Alloys exhibiting particular tendencies must necessarily be taken care of by suitable foundry technique.

39. The characteristics of the elements used in preparing aluminum alloys, and their effect on the soundness of castings made from each alloy, can be described only briefly. They involve such factors as methods of addition to the molten aluminum, temperature, whether added as a rich alloy and how such an alloy was prepared,¹³ purity of added element, and characteristics of the element itself. This latter factor is well covered by various publications, while the control of the other factors is best determined by studying the particular alloys in use.

40. The effect of impurities such as oxides and nitrides on the soundness of aluminum castings is still a debatable question. There is no doubt that such impurities are undesirable from the standpoint of the strength of the casting, and that they introduce machining difficulties. Whether such impurities do or do not affect pinhole porosity is still somewhat questionable, although considerable affirmative evidence is available.

41. It is logical to believe that small particles of impurities act as carriers for a considerable quantity of gas. Unless all the impurities are carefully removed before pouring a casting, the

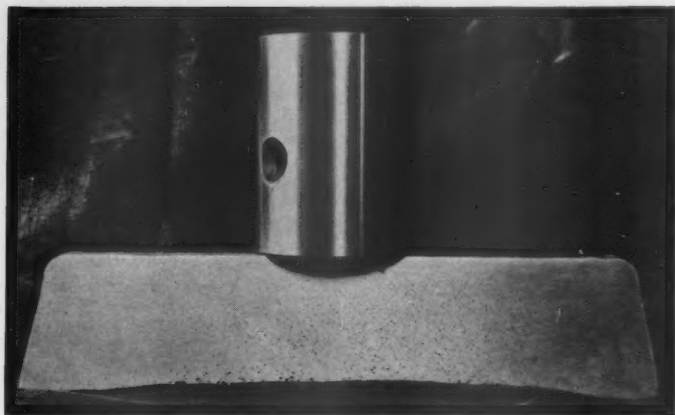


FIG. 5—MACHINED CROSS-SECTION OF ALUMINUM-ALLOY INGOT AND CASTING MADE FROM INGOT. POROSITY APPARENT IN THIS INGOT IS NOT APPARENT IN RESULTING CASTING.

particles carry this gas into the mold cavity and, as the metal solidifies, release the gas, forming small cavities or porosity. The presence of aluminum oxide in connection with many porous areas confirms this theory to some extent.

42. Generally speaking, those alloys which solidify over a comparatively large temperature range exhibit the greatest tendency toward shrinkage porosity. The aluminum-copper alloys are good examples of this condition. The low melting copper eutectic found in these alloys will solidify last and result in shrinkage voids unless feeding and cooling conditions are ideal. Aluminum-silicon alloys, because of their greater fluidity, even at temperatures but slightly above their melting point, are somewhat easier to feed and therefore are less likely to show porosity under identical foundry conditions.

Condition of Metal as Determined by Previous History.

43. Correct melting practice, fluxing and observance of foundry technique are beneficial, of course, in reducing unsoundness in castings but should not be depended upon to compensate entirely for certain inherent metal characteristics. The source of the metal used in the production of castings usually reflects on the resulting soundness.

44. As a case in point, the use of metal of unknown past

history often results in castings of questionable quality. Ingot made from fine sawings, borings, foil and scrap material of unknown origin, especially if at one time oily, greasy or wet, may contain considerable gas, oxide and harmful impurities which may be exceedingly difficult to remove by remelting. Although special metal treatments may be helpful, in such cases, there is never a definite assurance that they effect a complete cure.

45. Aluminum-alloy ingot often will contain porosity and surface shrinkage. This condition results from the fact that no endeavor is made to compensate for solidification shrinkage or to provide progressive solidification, either of which is important in an ingot for casting purposes. However, in the past many foundrymen have attributed pinhole porosity in castings to porosity and shrinkage in the ingot. From the foregoing discussion it is apparent that this is not a logical conclusion, and experiments have proven this point (Fig. 5).

EXPERIMENTAL DETERMINATION OF EFFECT OF FOUNDRY FACTORS ON SOUNDNESS

46. In order to determine experimentally the importance of the various foundry variables already discussed on the soundness of the resulting castings, numerous tests have been made in the foundry. All of these tests, a few of which are outlined herein, were conducted on a production scale; they were carried out in the plant melting room and foundry along with the production of commercial castings. The size of the experimental heats in all cases varied from 100 to 400 lbs.

47. The tests, therefore, were conducted to a great extent from the viewpoint of the practical founder whose desire is to obtain sound castings by means of simple and rapid methods. Consequently, the various methods of producing sound castings are evaluated by a consideration of these factors as well as the ultimate results obtained.

48. For test purposes several special patterns as well as regular production patterns were used. Among these was a slab 300 mm. long by 150 mm. wide graduated in steps 25, 18.8, 12.5, and 6.3 mm. thick. Several cylindrical discs from 130 to 250 mm. in diameter and 50 to 150 mm. thick were also used. For examining the various castings and grading them as to relative soundness and freedom from pinhole porosity, X-ray photographs were used in

many instances.¹⁴ The sectioning and machining of test castings to permit more careful study of the porosity also were resorted to in some cases.

METHODS OF SUPPRESSING PINHOLE POROSITY OTHER THAN FOUNDRY TECHNIQUE

49. Earlier in this paper we considered the production of sound aluminum-alloy castings by means of controlled foundry practice. It is the purpose now to discuss briefly a number of special metal treatments, including various fluxes, which have been suggested to improve the soundness of castings.

50. The basis for these various treatments is the belief that unsoundness in aluminum alloys is caused largely by the absorption of gas by the metal during remelting, processing, or reclaiming. Many of these treatments, although showing promise in laboratory tests, have failed to function on a production scale, while others are of such intricate nature as to be too difficult to use.

Fluxing Agents

51. Many of the methods for improving the soundness of aluminum-alloy castings employ some fluxing agent for the purpose of removing gas from the molten metal. In general, these fluxing agents are either active or inert gases, volatile chlorides, or stable metallic salts. The principal gases which find use as fluxing agents are chlorine and nitrogen. The action of these gases is either chemical, mechanical, or a combination effect tending toward the removal of the various gases from the molten aluminum. In the process, the gas is generally introduced at the bottom of the bath of molten aluminum through a perforated tube, the pressure being sufficient to cause the gas to bubble through the metal and escape at the surface.

Chlorine Gas.

52. Chlorine gas has proved to be an efficient fluxing medium, particularly for alloys which contain appreciable copper.¹⁵ This gas makes a very active fluxing material and apparently is quite efficient in removing gases introduced in the metal by poor melting practice. The action of chlorine is both chemical and mechanical. When introduced into molten aluminum it reacts chemically with many of the impurities and dissolved gases. Mechanical agitation

is provided by volatilization of the compounds formed as well as by the excess chlorine itself as it bubbles through the metal.

53. Chlorine gas fluxing does not appear to improve the mechanical properties of properly melted alloys. A considerable number of tensile tests have been made comparing chlorine fluxed metal with unfluxed metal. In no instance was there any appreciable difference in tensile strength and ductility between the fluxed and unfluxed metal.

54. The use of chlorine gas in a commercial foundry presents a number of difficulties. The gas in itself is extremely poisonous and chemically active, so that its use is limited to small units under careful technical supervision. This is not so much of a problem in a small foundry, where production is limited, as in a large foundry where an appreciable tonnage of a number of alloys is constantly in process of being poured into castings.

Nitrogen Gas.

55. Nitrogen gas, alone or in combination with chlorine gas, has not been found very successful as a flux.¹⁶ The action of nitrogen is essentially mechanical, lifting the small bubbles of occluded gases through the molten metal to the surface. Experiments using this gas alone as a flux showed but slight improvement in the appearance of machined surfaces. This improvement is not considered sufficient to warrant the use of nitrogen either by itself or in connection with chlorine.

Volatile Chlorides.

56. A second group of fluxing materials includes the volatile chlorides, of which titanium tetrachloride and boron trichloride are perhaps the most important. These materials generally are introduced in liquid form into the molten metal, volatilization taking place instantaneously and resulting in an effect very similar to that of fluxing with chlorine gas.

57. The use of such volatile chlorides with aluminum alloys, under certain conditions, combines a cleansing action similar to that of chlorine gas with the grain refining effect of titanium and boron. Experimental tests to date have indicated some possibilities for fluxes of this type. The mechanical properties of metal fluxed with titanium tetrachloride have shown a slight improvement when compared with unfluxed metal. Before these materials can be

used satisfactorily on a production scale, however, a more practical apparatus for introducing them into the metal will have to be developed.

Metallic Halides.

58. A number of foundry technicians advocate the use of metallic halides for the fluxing of aluminum alloys. The more common of these are the chlorides of aluminum, copper, chromium, lead, manganese, nickel and zinc.¹⁷ Of these, aluminum and zinc have been perhaps the most widely used of the group. Their use no doubt is beneficial in some instances, providing they are used absolutely dry. This detail, unfortunately, is not always observed, with the result that water vapor is introduced into the metal, resulting in more harm than good.

Metallic Chlorides.

59. Manganous chloride or zinc chloride, in contact with molten aluminum is partially reduced, the manganese or zinc alloying with the aluminum while the aluminum chloride formed serves as a cleansing medium. Fluxing with copper, nickel, tin, lead and chromium chlorides has also been tried with variable results.

60. The use of metallic chlorides such as mentioned does not appear to have a great possibility of application. In the first place, many of these materials are relatively costly. Also, most of them are hydrous and the water of crystallization must be removed before they can be used. The possibility of introducing metallic elements into the metal which are harmful to mechanical properties and to corrosion resistance must also be considered.

Alkaline Salts.

61. A fourth group of fluxes under consideration includes the salts of alkaline earth metals such as sodium, potassium, lithium and calcium, fluorides, chlorides, and sulphates.^{18, 19} Such fluxes are used in a great variety of combinations, depending upon individual experience and requirements. Their composition and application is too extensive to permit other than a brief discussion of their merits. They are used either as a cover for molten aluminum or as a chemical means of eliminating dross and gas. From this standpoint, a flux generally consisting of one or more chlorides and fluorides or cryolite has been found efficient.²⁰

Physical Methods

Double Melting.

62. A number of mechanical or physical methods have been suggested as a means of improving the soundness of aluminum-alloy castings. The most practicable of these that has been tried is double melting, that is, initial melting, slow solidification and subsequent remelting. The serious handicap to wide use of this method is the time required to complete the process. For this reason it can be used only for special castings in limited production.

Vacuum Melting.

63. Melting in inert gas atmospheres or in vacuum, to eliminate gas absorption by the molten metal as well as to reduce oxidation, also has been suggested. Very little experimental work with these methods has been conducted because of the difficulty of maintaining a satisfactory atmosphere in the melting furnaces available in production foundries.

Solidification Under Air Pressure.

64. The solidification of sand castings under air pressure has been carried out on a small scale. This practice definitely increased the apparent soundness of castings. This improvement, however, was not reflected in the mechanical properties. The apparatus and control required to successfully apply this method appear at this time to limit future applications.

DISCUSSION

65. It is evident, as has been pointed out, that proper control of certain factors and variables in the metal-handling process and in the foundry technique makes for soundness in aluminum-alloy castings. Apparently there is a growing tendency on the part of foundrymen to attempt to increase the soundness of such castings by fluxing or by special treatment of the metal. This action, of course, is commendable, providing foundrymen do not place too much attention on the use of fluxes as foundry "cure-alls" and lose sight of the elimination of the actual cause of the unsoundness.

66. Fluxes and special metal treatments will not correct all the effects of poor foundry technique or the difficulties imposed by complex casting design. It is logical, therefore, that the first steps

taken to enhance the soundness should be toward improving the foundry practice and, if necessary and practical, simplification of casting design.

67. It is recognized that in certain instances fluxing or special metal treatments, in conjunction with proper foundry technique, are advantageous in increasing the soundness of certain castings. Such treatments, however, must be carried out under controlled conditions or the soundness of the resulting castings will be impaired rather than bettered. (Fig. 6)

68. Of the various fluxes and treatments suggested for use with aluminum alloys, several have shown possibility of application

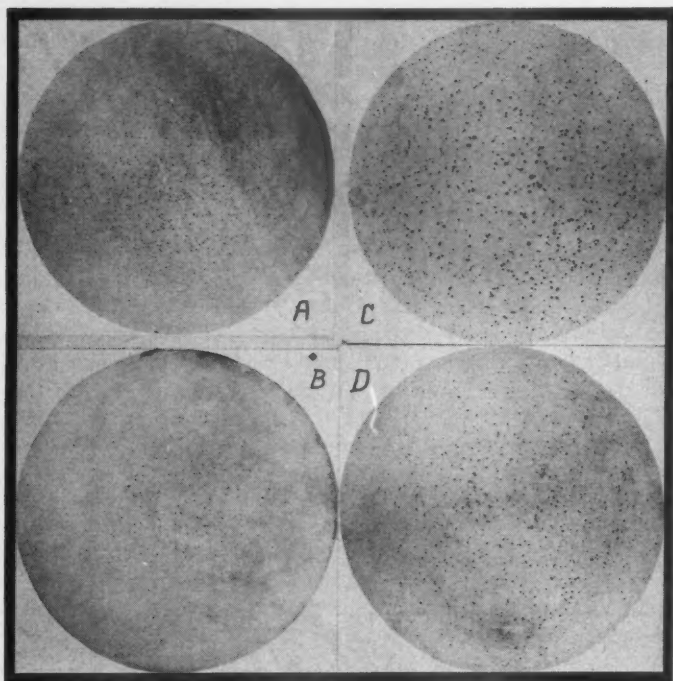


FIG. 6—MACHINED SECTIONS OF SAND-CAST ALUMINUM-ALLOY DISCS, 250 MM. DIAMETER, 150 MM. THICK, CAST WITH DIFFERENT FOUNDRY CONDITIONS. A: CHILLED SECTION CAST AT 1250 DEGS. FAHR. FROM UNTREATED METAL. B: CHILLED SECTION CAST AT 1250 DEGS. FAHR. FROM METAL PREVIOUSLY TREATED WITH CHLORINE GAS. C: UNCHILLED SECTION CAST AT 1250 DEGS. FAHR. FROM UNTREATED METAL. D: UNCHILLED SECTION CAST AT 1250 DEGS. FAHR. FROM METAL PREVIOUSLY TREATED WITH CHLORINE GAS.

in the foundry. Chlorine gas and certain of the chloride and fluoride salts are regarded by many foundrymen as effective fluxes. Double remelting with an intermediate slow solidification appears to be a reliable treatment in many cases where time and melting furnaces are not limiting factors.

CONCLUSIONS

69. The logical method of improving the strength and soundness of aluminum-alloy castings consists in the rigid observance of certain factors involving foundry technique. Among these factors are the following:

(a) Maintenance of lowest possible melting and pouring temperatures.

(b) Selection of proper melting equipment and control of melting practice.

(c) Molding practice which provides for ample feeding, proper distribution, and intelligent control of rate of solidification of the metal in the mold.

(d) Choice of alloys, alloying constituents and condition of metal as determined by previous history.

70. Generally speaking, the use of fluxes and other metal treatments alone will not increase the soundness of aluminum-alloy castings, and at best give uncertain results.

71. Certain metal treatments, such as fluxing with chlorine gas or metallic salts, or double melting with intermediate slow solidification, when used in conjunction with proper foundry technique often will improve the strength and soundness of castings.

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